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Review

Biomechanics in Orthodontics Loop Mechanics - A Review

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Abstract

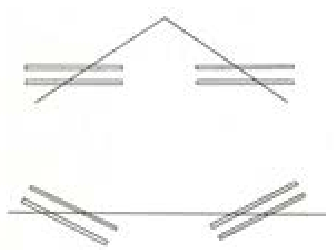
Extraction space closure is an integral part of orthodontic treatment, which demands a thorough understanding of the biomechanics. In the pre-adjusted edgewise technique, retraction is achieved with either friction (sliding) or frictionless mechanics. In the former, the wire and position of the bracket are important factors in tooth movement but the binding between bracket and archwire offsets the simplicity of friction mechanics. This slows tooth movement, compromises the delivery of desired force levels, causes anchor loss and may be associated with undesirable side effects such as uncontrolled tipping and deep bite. A review of frictionless mechanics in general and most commonly used loops in retraction has been highlighted in this article.

***Keywords**: Canine Retraction; Loop Mechanics; Variable Modulus Orthodontics.*

BIOMECHANICAL CONSIDERATIONS IN BENDING LOOP FREE ARCHWIRES[1]

On engaging the archwire into the slot of the bracket, the tooth movement occurs when at least one angular relationship exists (Figure 1).

Figure 1. Straight slots and angulated wire can produce force systems identical to straight wire and angulated slots



Illustrates that in both the cases with aligned slot and bent wire or angulated slot and straight wire, the wire bracket angles remain identical. With straight wire and angulated slots, prescription brackets are indicated. Here there is intentional canting of bracket slots during placement on the crowns or the angles that result from various tooth positions in a malocclusion regardless of the plane of space. On observing, they found, the result to be the same in both situations and therefore the same force systems, thus further concluding that regardless of the slot size or inter-bracket distance, the relative values will remain constant.

A two-bracket system is considered to be ideal from a scientific point of view. An angular relationship between the wire and bracket is achieved by activating it intraorally with Tweed Loop forming plier. The phenomena of primary response are observed in bracketed teeth immediately adjacent to the bend. These bends are usually not incorporated during the initial bracket alignment phase because the malocclusion at this stage produces wire bracket angles that automatically results in given force systems. These force systems may not be altogether desirable. Intraoral activation should be considered following the basic bracket alignment.[2]

An initial tooth movement that takes place is referred to as primary response, considering that in time other responses may follow which are undesirable. These later responses are commonly termed as secondary responses. These secondary responses are avoided or at least kept to a minimum by eliminating bends on completion of the primary response. It is emphasized that the force systems presented technically apply to a two-bracket system, but for the sake of daily clinical use, an acceptable compromise is offered. Further clarification of primary versus secondary response is explained in (Figure 2).The roots adjacent to the extraction sites have been aligned by placing gable bends(later referred to as centre bends). These bends tend to create equal and opposite moments at the brackets on either side which leads to root alignment. If the wire were allowed to continue to act following root alignment, other undesirable responses would begin to take place. These secondary responses would consist of excessive movement of the apexes toward each other as well as flaring of the lower incisors. A reverse curve of speed in the same arch would produce equal and opposite moments at each end of the arch, resulting in immediate flaring of the incisors.

Figure 2. Locating a centre bend between the canine and second premolar will produce a primary response in these teeth. In this case, the response is root alignment

The placement of a specific bend creates forces and moments that will have their primary effects on the teeth adjacent to the bend while limiting the other undesirable effect. These adverse effects can be eliminated by removal of the bend immediately following the primary response. Although four wire-bracket angles are presented, only two of them are usually midpoint between two brackets.

These have the advantage of delivering the forces and moments necessary permitting the orthodontist to create them intraorally with considerable ease. All four of these angles can be created intraorally with Tweed Loop pliers (Figure 3), are shown in (Figure 4 (i-iv)). The figures illustrate both the aligned bracket slots and the prescription slots. Because both eventually produce the same force system, only the aligned slots are demonstrated for intraoral activation to form a specific wire-bracket angle and their characteristic force systems. The force systems associated with each wire bracket angle are illustrated in (Figure 4 (v-viii)).[3,4]

Figure 3. Tweed Loop pliers can produce consistent angular bends during intraoral activation

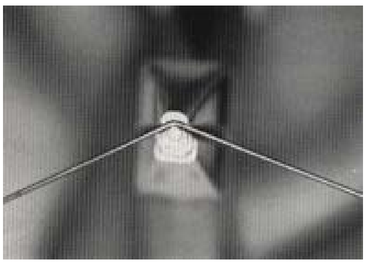


Figure 4(i). The centre bend is located at the midpoint

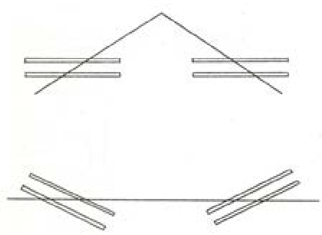


Figure 4(ii). An off-centre bend located at one-third position on the inter-bracket span

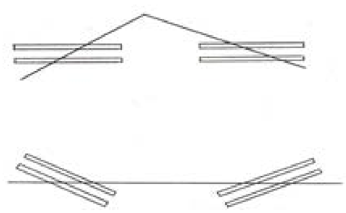


Figure 4(iii). An off-centre bend located at the bracket-beyond the "one –third" position in cantilever

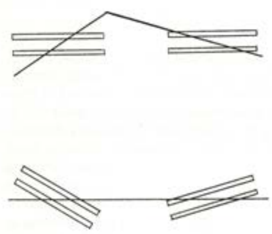
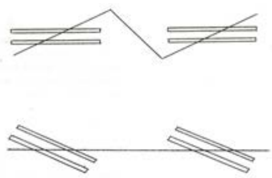


Figure 4(iv). Two off-centre bends located at each bracket, but on opposite sides



It should be noted that whenever the moments are not equal and opposite, forces are introduced in order to comply with the requirements of static equilibrium. Whenever one moment is different in magnitude from the other, a net moment tends to occur in the opposite direction because of the couple. It is this couple that keeps the teeth in equilibrium. As an orthodontist, one does not have to make the effort to comply with the requirements for equilibrium. This is done when activation takes place by engaging the wire into the bracket slots. However, an understanding of forces produced is essential in order to avoid or control side effects (Figure. 4(v) to 4(viii)) show that each wire brackets angle produces specific movements.

Figure 4(v): illustrates equal and opposite moments and is, therefore, an effective method to parallel roots in extraction cases.

Figure 4(v). The center bend produces equal and opposite moments

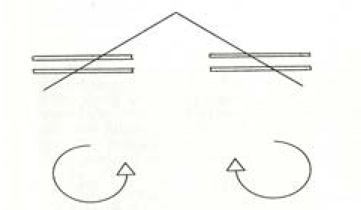


Figure 4(vi) may be used to treat various problems associated with extraction treatment, including the control of molar position and the buccal-lingual positioning of the central grooves. This cantilever is also excellent for intrusive movements because a single force at one bracket characterizes it.

Figure 4(vi). An off-centre bend located at the bracket closest to the bend and equal and opposite forces at each bracket. This represents a cantilever system

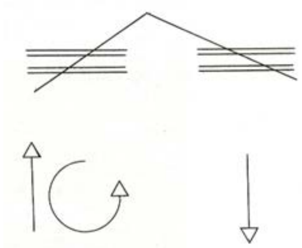


Figure 4(vii) illustrates an effective method to initiate cuspid retraction with good anchorage control since both brackets produce initial moments in the same direction.

Figure 4(vii). An off-centre bend located at the bracket-beyond the "one-third position-produces unequal moments in the same direction and forces larger than those in the cantilever

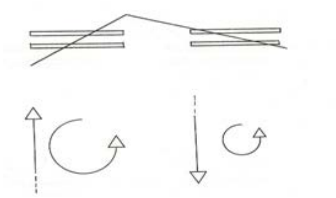
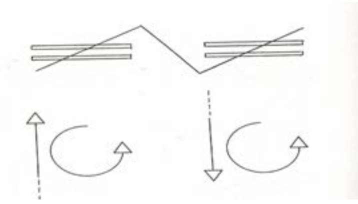


Figure 4(viii) shows a technique for anchorage preparation used in the treatment that combines tip-back bends with anterior labial root torque. However, this particular wire bracket relationship produces the greatest magnitude of force due to moments in the same direction that require a balancing couple. These larger forces produce the couple necessary in compliance with the requirements of equilibrium. This wire bracket relationship should be used with caution in the vertical plane of space because it could result in the need for high-pull headgear and patient cooperation

Figure 4(viii). Two off-centre bends (step) producing equal moments in the same direction and the largest magnitude of force in the four wire/bracket relationships presented



RETRACTION AND PROTRACTION OF TEETH[5]

Anchorage considerations form a crucial part of the treatment plan during space closure. Depending on what type of anchorage is needed, the treatment plan is formulated. The wire bracket angle is chosen depending on the need of the patient. For example, in cases of cuspid retraction, which wire bracket relationship, would best serve for desired tooth movement is determined.

The inter-bracket distances is quite small in a fully bonded case. Notice in figure 4(i-v) to 4(v-viii) various degrees of anchorage are available depending on the "differential" moment. Centre bend (figure. 4(v), with the moments equal and opposite, would not have an effective reciprocal anchorage. If a canine retraction case is begun with the off-centre bend seen in (figure. 4(vii), the movement will be initiated with moments acting in the same direction, thus providing better initial anchorage. Since the inter-bracket distances are quite small, there is not a great deal of difference from the force system produced with a centre bend because just a small amount of canine movement quickly alters the force system since the wire bracket angle quickly changes.

The greater the distance the bend can be placed from the centre, the greater the difference in the magnitude of the moments at the brackets adjacent to the bend. Ironically, this means that when more anchorage is desired than can be obtained in a full strap-up with the use of an off-centre bend, this increase in Anchorage can be better obtained by actually avoiding the placement of brackets on the second premolars (Figure. 5), assuming a first premolar extraction case. This allows further distal displacement of the bend from a centred position, resulting in greater differential moments. The largest moment occurs at the bracket or tube located closer to the bend. Since the placement of the bend just mesial to the molar tube instead of mesial to the second premolar bracket results in a greater difference between the moments, it actually enhances anchorage. It should be noted that when the bend is in the centre, the moments are equal and opposite, but a slightly off-centred position bend will create a difference in the magnitude of the moments. As the distance of this bend is increased from the centre, the differential continues to increase, and thus the reason for not always bonding every tooth.

Figure 5. Increasing the wire span by not bracketing the premolars creates a greater "differential" in moments with an off-centre bend located at the molar tube

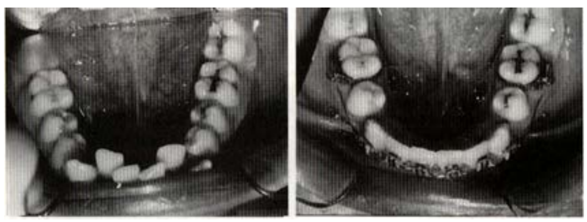


Figure 6(i). Initial force system during canine retraction

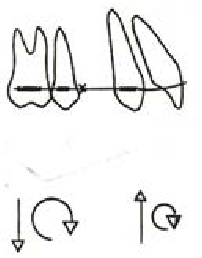


Figure 6(ii). Force system following some canine retraction

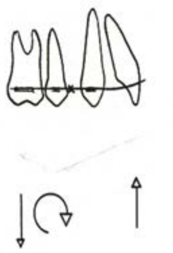


Figure 6(iii). Force system prior to final space closure

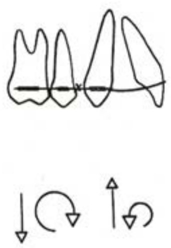


Figure 6(iv). Force system following space closure. (Technically, these moments are unequal due to the angulated canine bracket)

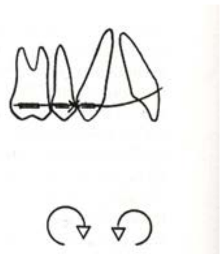


Figure 6(i) to 6(iv), illustrates that the change in force systems during retraction of canines with elastics on a continuous archwire. These figures do not precisely reflect the angles but show the change in the force systems gradually with space closure. During canine retraction, as the bends are located distal to the one-third position (in reference to inter-bracket distance), two moments are produced which act in the same direction, although they are not of equal magnitude. This results in the maximum anchorage at the time retraction is initiated. As the canine is slowly retracted, although the bend remains in its original position, it now lies closer to the centre because the canine bracket is moving toward the bend (Figure 7). As long as the power chain used for canine retraction is not over-activated, the larger moment holds the anchor tooth in an upright position. If the bend is just mesial to the second premolar bracket, the second premolar is held in an upright position.

Figure 7. Canine retraction with premolars bracketed. Note the small inter-bracket distance

Figure 8. Canine retraction with premolar bracket absent on one side

An off-centre bend at the molar tube will produce more effective anchorage than an off-centre bend on the opposite side mesial to second premolar bracket (Figure 8). In both cases, the canine tips and moves toward the bend. If the second premolar is not bracketed, the canine tipping is somewhat greater because of the great difference in the magnitude of the moments present on the canine and molar. As canine retraction takes place, the smaller canine moment gradually disappears, and with further movement, a small moment reappears on the canine, but in the opposite direction. Thus, anchorage diminishes as canine traction takes place. The force system is undergoing constant change and gives maximal anchorage when it is needed most and diminishes as space is closed. Throughout space closure, the largest moment continues to be present on the anchor side of the extraction site. The bracket or tube closest to the bend contains larger moment.[6]

Finally, when space is closed and the anchorage is no longer a requirement, a centre bend relationship occurs. If a second premolar bracket is not present (Figure 9), completed space closure cannot result in a centre bend relationship because the original off-centre bend placed mesial to the molar tube still exists as an off-centre bend. Intraoral activation of the wire just distal to the canine bracket creates the equivalent of a centre bend because an off-centre bend mesial to the molar tube and another just distal to the canine bracket each produces opposite angles and therefore opposite moments (Figure 10). The concept of root alignment using two off-centre bends also has other benefits. If first premolars are removed while second deciduous molars are still present (Figure 10), canine retraction can still be accomplished with the off-centre bend placed mesial to the molar tube and an additional bend placed distal to the canine bracket following space closure. This second bend, again, is placed to provide equal and opposite angles (Figure 10). As stated earlier, two off-centre bends can be placed in this manner to produce the same force system as a centre bend would that creates equal and opposite moments. Similarly, when a second molar brackets fall off (Figure 9), the original off-centre bend mesial to the second premolar can be removed and another off-centre bend placed just mesial to the molar tube. Then, following space closure, a bend can again be placed distal to the canine bracket to provide equal and opposite moments for root alignment.

Figure 9. A centre bend and two off centre bends producing the same force system. B. A centre bend following canine retraction with the second premolar bracketed. The bend is located mesial to the second premolar bracket

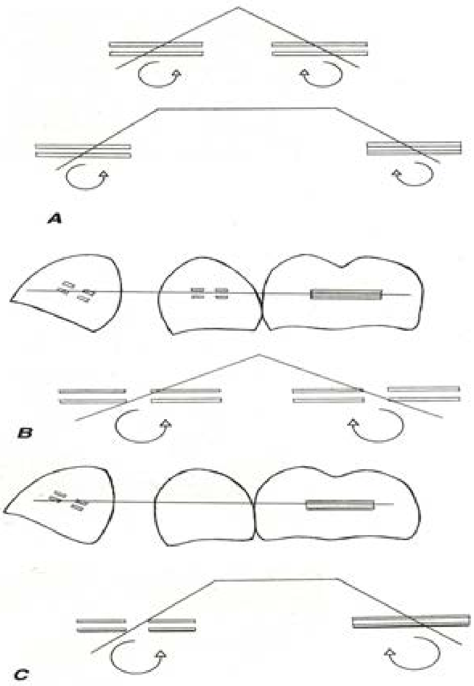
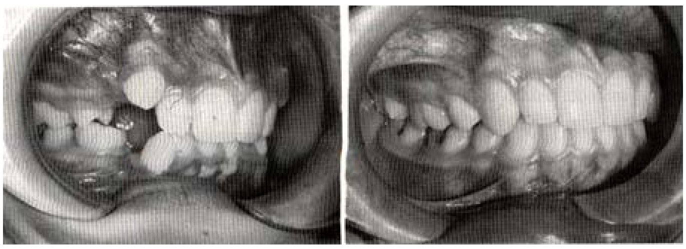
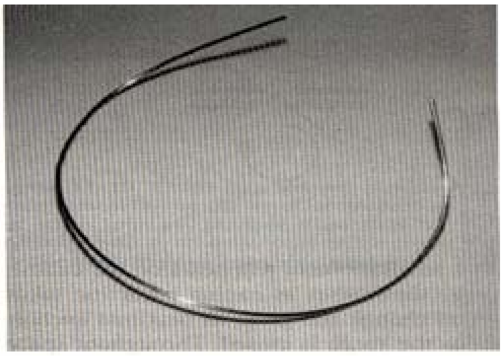


Figure 10. Canine retraction prior to eruption of second premolars



Following the canine retraction, anterior alignment is accomplished. If there remains the need for anterior retraction, it must be determined how much tipping versus bodily movement is required. If only tipping is required, a loop-free archwire, as shown in (Figure 11), may be used. The curvature at the distal of the wire will provide anti-rotational moments on the molars during space closure while the curve of Speed in the archwire will tend to control tipping by producing a centre of rotation near the apices of the anterior teeth. A power chain elastic will provide the force for space closure, but there should be no critical anchorage requirements.

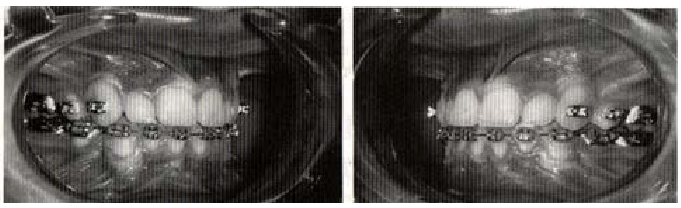
Figure 11. Loop free wire containing a curve of speed and posterior curvature for control of molar rotation



Two off centre bends following canine retraction of the anterior teeth require considerable anchorage, an archwire that comes out of the molar tube and bypasses the teeth in the buccal segment, gingival to the brackets, and then inserted into the incisor brackets, can be utilized. This bypass is necessary only when teeth in the buccal segment are bracketed. The bypass creates the equivalent of a 2x4 appliance and permits the development of posterior anchorage by creating a relatively large moment at the molar with a curve of Speed in round wire. The curve in the wire permits the wire to slide through the molar tubes during anterior retraction of teeth while at the same time avoiding any torque in the incisor brackets. Because both tip back-bends and curves, produce differential torque in partial strap-ups, they provide anchorage while retracting anterior teeth. The result is the tipping of the incisors. In patients needing incisor root torque, care is needed in the application of moments because they tend to flare incisor crowns and strain posterior anchorage. The result may be loss of the Class 1 correction previously obtained.

A solution is to place an equal and opposite moment at the other end of the archwire. Crown movement tends to precede root movement, and therefore teeth will move forward if only anterior lingual root torque is placed into a rectangular wire. However, if an equal amount of torque is placed in the posterior providing a moment in the opposite direction, the Class 1 correction will be maintained because of anterior and posterior teeth being unable to move in opposite directions. This assumes that the wire is tried back at the molar tubes. When crown movement is prevented in one direction, the moment present results in root movement in the opposite direction. Thus, during the anterior lingual root movement, mesial root movement is produced at the same time in the posterior while preserving a Class 1 relationship. All wires should be removed periodically during treatment (Figure 12)[7] this results in seating all cusps prior to appliance removal.

Figure 12. Maxillary archwire and anterior brackets removed while cusps are seated



Protraction is nothing more than retraction in reverse. In patients with missing second premolars, to protract the molars a loop-free wire would be used but the off-centre bend would be located just distal to the first premolar bracket in order to provide the larger moment in this area. The molar now contains the smaller moment and will tip forward during the closure, just as the canine tipped back when it contained the smaller moment. Everything that was discussed during canine retraction remains the same except that the force system is "*turned around*". The bend is always placed against the bracket of the tooth, whose movement we wish to minimize resulting in the smallest moment undergoes the tipping, and the transitional force system (Figure 6(i) - to - 6(iv)), results in a gradual loss of anchorage followed by alignment of the roots when spaces are finally closed.

VARIABLE-MODULUS ORTHODONTICS[8]

Optimal Forces and Wire Stiffness

On insertion of a plain wire into brackets for the purpose of alignment, the force does not remain constant as the teeth move. On full engagement, the forces may be excessive, leading to undermining resorption and concomitant tissue damage, including a reduction in pain thresholds. With tooth movement, the force range becomes optimal, with direct bone resorption proceeding and minimal lowering of pain thresholds. If the wire is left in place, the forces will be further reduced and a suboptimal zone is reached in which tooth movement will continue but rates of tooth movement will be smaller and less efficient. Finally, because of dissipation of force, a threshold has been reached and below it, in a subthreshold zone, no tooth movement whatsoever occurs. A straight alignment arch produces a range of force values and in many situations from excessive to subthreshold.

Because of the changing force values and geometries as an appliance works out, a clinician will notice that a light alignment arch may move the teeth only partly to their final position. A typical solution to this problem has been to use a series of increasingly heavier alignment or leveling arches to complete the tooth movement (for example, 0.016 inches followed by 0.018 inches followed by 0.018 by 0.025 inch). What an orthodontist is accomplishing might be called a "replacement approach", which is nothing more than varying the force at the time of insertion by using wires of increasing stiffness that is, increasing the load-deflection rates in sequential wires. Another approach is the one in which one wire is used with low load deflection rate so that the force magnitude is delivered more constantly. This allows the dentist to approach optimal force magnitudes and to negate excessive and subthreshold force zones. This approach in alignment could be referred to as the "constant-force approach". It either can be achieved with plain wires or looped configurations.

VARIABLE-CROSS-SECTION ORTHODONTICS[9]

The selection of the proper wire size should be primarily based on the load-deflection rate required in the appliance. Secondarily, it is dependent upon the magnitude of the forces and moments required. It may be believed that one reason that increasingly heavier wires are needed in a replacement technique is that one is eliminating the play between the wire and the bracket. In an edgewise appliance the ligature wire minimizes a great amount of the play in a first-order direction since wires seat fully within the brackets. With narrow edgewise, brackets play may be present in a second-order direction, but even these the ligature tie tends to minimize play, even with smaller cross-section wires. One, therefore , does not select a 0.018-inch wire over a 0.016 inch primarily because of the difference in play.

A second reason that a wire may be selected is the belief that the smaller the wire, the greater will be the amount of maximum elastic deflection possible. In other words, the smaller the wire, the more one can deflect it without permanent deformation. This is true, but maximum elastic deflection varies inversely with the diameter of the wire. A 0.016-inches wire would only have 1.15 times as much maximum elastic deflection as a 0.018-inches wire; therefore, the differences are negligible from a clinical point of view. If the differences are two to one, as in 0.010 inch versus 0.020 inches, then, of course, this factor becomes clinically significant.

The major reason that the orthodontist should select a particular wire size is the stiffness of the wire or its load-deflection rate. In a replacement technique, for instance, one might begin with a 0.014-inches wire, which, deflected over 2 mm, and could give the desired force. After the tooth has moved 1 mm, the wire can be replaced with a 0.018-inch wire, which would give approximately the same force with 1 mm of activation. Small changes in cross-section produce large changes in the load-deflection rate since the load-deflection rate varies as the fourth power of the diameter in round wires. In bending, the stiffness or load-deflection rate is determined by the moment of inertia of the cross-section of the wire with respect to the neutral axis.

The clinician is interested in the relative stiffness of the wires that he uses, but he has neither the time nor the inclination to use engineering formulas to determine the stiffness. For that reason, a simple numbering system has been developed, based on engineering theory, which gives the relative stiffness of wires of different cross-sections if the material composition of the wire is the same. The cross-sectional stiffness number Cs uses 0.1 mm. (0.004 inch) round wire as a base of 1. A 0.006-inches wire has a Cs of 5.0, which means for the same activation five times as much force is delivered. Manufacturing variation in wires or mislabelling of wires obviously can significantly alter the Cs number. Two Cs numbers are needed for rectangular wires- one for the first-order direction and the other for the second-order direction.

Wire with a cross-section of 0.016 inches has a number of 256, which implies that, for an identical activation, it would deliver 256 times as much force as a 0.018 by 0.025-inches wire in a first order direction is 1,865. Since 0.016 inches has a number of 256, a 0.018 by 0.025-inches wire in a first-order direction delivers 7.3 times as much force for the same activation. It has been assumed until now, for purposes of comparison, that the wire configuration and the alloy that it is constructed of are identical and that only the cross-section is being varied. To compare any two sections of wire for stiffness, one has only to divide the cross-section stiffness number of one into the other.

VARYING THE MATERIAL RATHER THAN THE CROSS-SECTION[10]

The cross-sectional stiffness number can be useful in being more precise in determining the stiffness of appliances only if the same alloy is used. The over-all stiffness of appliance (S) is determined by two factors; one factor relates to the wire itself, (Ws) and the other is the design of the appliance (As):

S = Appliance load-deflection rate

S = Ws. As

Ws = Wire stiffness

As = Design stiffness factor

In general terms,

Appliance stiffness = Wire stiffness. Design stiffness

Wire stiffness is determined by two factors- the cross-section and the material of the wires:

Ws = wire stiffness number

Ws = Ms. Cs

Ms = Material stiffness number

Cs = Cross-sectional stiffness number

In general terms,

Wire stiffness = Material stiffness. Cross-sectional stiffness

Wire stiffness is determined by a cross-sectional property, such as the moment of inertia, and a materials property, the modulus of elasticity.

A numbering system is used to consider relative stiffness based on the material. The material stiffness number (Ms) is based on the modulus of the elasticity of the material, which is the property that determines its stiffness. Since steel is the most commonly used alloy, its (Ms) number has been arbitrarily set at 1.0. This is based on an average modulus of elasticity of 25,000,000 p.s.i.81 although the modulus of elasticity is considered a constant, it should be remembered that the history of the wire (particularly that of the drawing process) may have some influence on the modulus. Furthermore, differences in chemistry may make small alterations in the recorded modulus. For practical clinical purposes, however, the material stiffness number (Ms) can be used to determine the relative amount of force that a wire will give per unit activation.

TMA has a (Ms) number of 0.42, which means that, for the same appliance and wire cross-section, a given activation delivers approximately 0.4 as much force as steel. Nitinol would deliver 0.26 as much force as comparable wires of stainless steel. Elgiloy wires deliver slightly more force than comparable wires of stainless steel but, for all practical purposes, this increase is negligible. In addition to new alloys, braided wires have been introduced into orthodontics. Braids take advantage of smaller cross-sections, which have higher maximum elastic deflections and, in the process, produce wires that have relatively low stiffness. If one were to pretend that a braid was a solid wire, and if the nominal cross-section wire used, one could establish an apparent modulus of elasticity. Based on apparent modulus, the material stiffness numbers were found for representative braided wires. For instance, a 0.018-inch Respond wire braid has an ms of 0.07 and delivers only 0.07 the force of a 0.018-inch steel wire.[11]

One could change the load-deflection rate, maintain the same wire size, and vary the load-deflection rate as significantly as by altering the cross-section. If the cross-section of 0.018 by 0.025-inch wire is to be maintained and Ws number is to be calculated then, the Ms was multiplied by the Cs number. For example, in a second-order direction for TMA

Ws= Ms. Cs

Ws= 42. 967

Ws= 406. 1

TMA wire with dimensions of 0.018 by 0.025 inch has a stiffness number of 406.1, which is equivalent to a 0.018 inch round steel wire. Nitinol wire with dimensions of 0.018 by 0.025-inch has a stiffness number of 251.4, which is similar to 0.016-inch steel wire. Braided wire with dimensions of 0.018 by 0.025 inch (Ss = 75.4) is similar to a 0.012 inch steel wire. One can obtain a full range of forces by varying the material of the wire and keeping the cross-section the same. The ratio of the smallest wire stiffness number to the largest is greater than 10:1.

ADVANTAGES OF VARIABLE-MODULUS ORTHODONTICS[12]

1. It allows the clinician to determine the amount of play that is required before selecting the wire. In some instances, more play is needed to allow freedom of movement of brackets along the archwire. In order situations, very little play is required to allow good orientation and effective third-order movements. Once the desired amount of play has been established, the desired stiffness of the wire can be produced by using a material with a proper material stiffness.

2. The variable-modulus principle allows for the use of oriented rectangular wires or square wires in light force, as well as heavy force applications and stabilization. A rectangular wire orients in the bracket and hence offers greater control in delivering the desired force system. It is easier to bend since one can carefully check the orientation of the wire and, more importantly, when placed in the brackets it will not turn or twist so that forces are dissipated in improper directions. Rectangular wires allow for the delivery of moments as well as forces so that during the alignment procedure better control is maintained over the roots. The ability to produce moments and forces at the bracket instead of single forces, as with round wires, has a definitive advantage in alignment procedures.

Overall, the principle of variable-modulus orthodontics reduces the number of archwires needed for alignment since bracket play is eliminated wires work more efficiently because of their orientation and their ability to be preferentially oriented and in many cases because of the increased maximum elastic deflection of the newer alloys that are used.

In instances where both first- and second-order movements are required, the ground wire might well be the cross-section of choice. A much lower stiffness is available for similar cross-sections. For example, a 0.018 by 0.018-inch square stainless steel wire has a wire stiffness number of 969 versus 410 for 0.018 inches round.

The minimization of friction between the archwire and the bracket is another advantage of round wire in some instances. The major disadvantage, of course, is the lack of orientation of round wire. Although more complicated, this problem can be solved by the placing of orientation extensions or loops to prevent rolling.

The decision of slot size for the edgewise appliance has been debated over a number of years. When steel was the only material available it could be argued that a smaller slot (0.018 inches) would allow the use of wires that orient and have lower stiffness. Now, with the potential of varying the modulus, it appears that the larger slot size (0.022 inches) is the more desirable since one is no longer dependent on wire size for stiffness. A disadvantage of the 0.018-inch slot is that in many instances insufficient play between the wire and the bracket is present in applications where a heavier wire is needed. Furthermore, the use of a larger slot allows for preferential orientation, so that ribbon wires can be employed.

THE WIRE-STIFFNESS NUMBER[13]

In the past when the orthodontist varied stiffness by cross-section with experience, he developed a feel for the force produced by wires of different sizes. The selection of the proper wire was much simpler since only one material (steel) was used. Even if the clinical feel was somewhat inaccurate, 0.018-inch wire always produced more force than 0.016-inch wire. Now, since the clinician can vary both cross-section and material, the selection of wire becomes much more difficult. Large cross-sections can deliver much lighter forces than smaller cross-sections. It was because of this difficulty that the numbering system was developed. The stiffness of an orthodontic appliance or a component of an appliance is determined by the wire itself and the appliance design. The stiffness of the wire is determined by two factors- the modulus of elasticity and the cross-sectional geometry of the material. Both of these values could be given to the clinician in engineering terms. For example, the modulus of elasticity of steel is 25 x 106 psi. In addition, the moment of inertia is 3.22 x 10-9 in. (0.016 inch round wire). The product EI = 8.05 x 10-2 in.-Ib. represents the stiffness of the wire. In a similar manner, in torsion G = 1.0 X 107 psi, J = 6.43 X 10-9 in, and GJ = 6.43 X 10-2 in. –Ib.

One could use the values for E, I, G, and J and the products EI and GJ to denote the stiffness of orthodontic wires. To simplify and to make available to the clinician the information required, a more meaningful and practical numbering system was established. Normalization is based on giving the average stainless steel modulus of elasticity (25 x 106 psi.) a Ms of 1. The moment of inertia of 0.004 inches (0.1 mm.) is also given a Cs of 1. In this system, the orthodontist is comparing any existing or new alloy 6 with stainless steel, which he is familiar with my experience, in applying the ms number. In a similar manner, the Cs number relates to a 0.004-inch wire. Normalizing the values has a considerable advantage for the clinician. The numbers are smaller than EI and are unitless. For an 0.016 inch round stainless steel wire,

Ws Ms x Cs

Ws = 1 x 256 = 256

By normalizing the values, one finds that 256 apply in tension, bending, and torsion, which is a further advantage and simplification. In most of the materials that we use in orthodontics, there is a constant relationship between different materials in their stiffness in the tension, bending, and torsion. In using the material stiffness and the cross-sectional stiffness numbers, one makes a meaningful comparison to a base (steel and 0.004 inches), which gives greater meaning to the stiffness number. Note that very different cross-sections deliver similar forces for any given activation. Wire stiffness numbers under 50 include 0.0009 inch stainless steel (Ws 26), 0.0175 inches Respond (Ws 25), 0.015 inches Twist-Flex (Ws 35), and 0.016 by 0.022 inches D rectangular (41, 30). It would be advantageous that the wire-stiffness number be placed on packages of orthodontic wires that are distributed for clinical use. This would allow the orthodontist to know exactly what might be expected from a wire. It is not enough to label a wire 0.018 inch since 0.018 inch wire of steel, TMA, and nitinol and braided wires (Respond) may have respective wire stiffness numbers of 410, 172, 107, and 25. Since there may be considerable variation between the nominal cross-section of the wire (the size listed on the package) and the actual cross-section of the wire (the size listed on the package) and the actual cross-section, it would be helpful to use actual cross-sections to determine the wire-stiffness number. Although the introduction of new materials adds to the complexity of orthodontics, a new potential is available which may allow the clinician to achieve results that may have been more difficult before. The use of a standardized numbering system may help to simplify and avoid some of the confusion inherent in the proliferation of new cross-sections, alloys, and braided wires.

SELECTING THE PROPER WIRE[14]

Three factors that are considered when selecting an appropriate wire for a clinical application: stiffness, maximum force or moment, and maximum elastic deflection. In developing the variable-modulus concept of treatment, only stiffness of wire is discussed. Although wires may be comparable in stiffness, (Ws numbers) they may vary considerably for the force that can be delivered. Many of the new alloys and braids can be activated at least twice the number of stainless steel wires so that higher force ranges can be produced than is possible with steel wire of the same stiffness. Furthermore, a 0.018 by 0.025-inch direct wire could efficiently align irregularities by the eruption but would not deliver 2,000 to 3,000 Gm/mm for canine root movement. A 0.018 by 0.025-inch TMA wire, for example, could work efficiently in this range.

Because of the larger maximal elastic deflection of the newer wires, it is usually possible to complete alignment procedures with one or two wires. A scheme of leveling (alignment) possibilities is given in Table VI. Ws numbers are listed after each wire; the first number is first order and the second is second order. Depending on the amount of the discrepancy, initial wires are chosen based on stiffness. A large discrepancy requires Ws numbers under 50. Using the constant force approach by over contouring wires, one may eliminate the need for an intermediate wire or retying the arch. Stiffness increases with the initial leveling wire or retying the arch from sequence 1 through 6. Ribbon wire suggestions are given where preferential orientation is desirable, favoring the first-order movement. These recommendations are based on the use of an 0.022-inch slot which allows sufficient play for tooth movement with 0.018-inch occlusal-gingivally dimensioned wires and adequate orientation with an edgewise wire. The 0.022-inch slot also allows the use of ribbon wires for more edgewise wire. The 0.022-inch slot also allows the use of ribbon wires for more efficient first-order corrections. If less pay is required for torque delivery on incisors, the final wire can be larger (0.021 by 0.025 inch) or inserted as a ribbon (0.020 by 0.016 inch). Heavier steel wires can be indicated if more rigidity is required, as in a stabilizing arch or when higher forces or moments are required. One example of the latter is a root spring delivering over 4,000 Gm /mm, which is used to purposefully displace an arch forward. Normally, the rigidity of steel edgewise wires is not required and, if used, should be relatively passive.[15,16]

CONFLICTS OF INTEREST

The author declares no conflict of interests.

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