The Mechanics Of The Segmented Arch Techniques

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Any orthodontic appliance reflects certain concepts and assumptions which the designer has made concerning the nature of tooth movement and the objectives of treatment. In very general terms, segmented arch procedures have been developed in order that continuous forces may be utilized for tooth movement without the loss of control.

As an orthodontic appliance is activated, the operator potentially has control over three variables which can determine the success of his adjustments. The first of these is the *moment to force ratio;* the second, the *magnitude of moment* or *force* used; and third, the *constancy* of the force or moment.[1] Since, by varying the moment to force ratio, various centers of rotation are produced, the ability to control tooth movement of any type is dependent upon the potential of an appliance to deliver the proper moment to force ratio. To better visualize the significance of the moment to force ratio one might imagine an edgewise vertical loop which is used for the retraction of the anterior teeth. The opening of the loop produces a force. If lingual root torque is incorporated into the anterior segment a moment will also be produced. It is the ratio between the lingual force and the torque (moment to force ratio) that will determine how the tooth will move, that is, where its center of rotation will lie during retraction.[2]

The quantitative response clinically is determined by the two other factors in the force system, the magnitude and constancy of the forces. An optimal force magnitude is one which will rapidly move teeth with a minimal lowering of the pain threshold and with minimal tissue damage. If force levels are too low, the rate of tooth movement will be sharply reduced or if they are too high, tissue damage and lower pain thresholds may ensue.[3,4,5]

Force constancy refers to the ability of an orthodontic appliance to maintain the same level of force during tooth movement. A constant force is a special type of continuous force where the force magnitude does not change. This is far different than the situation observed with a typical orthodontic spring or loop where there is a sharp reduction in force during tooth movement. Technically the force-deflection rate defines the force constancy of an orthodontic spring.[6] Since few orthodontic mechanisms can deliver perfectly constant forces, it might be said that as the force-deflection rate approaches zero the force becomes more constant.

The segmented mechanisms which will be subsequently described have been designed to control tooth movement with known moment to force ratios and to aim at optimal biologic response by the delivery of relatively constant forces at an optimal magnitude.[7]

Attempts will be made in this publication to describe some typical segmented arch mechanisms in the treatment of an extraction case. Similar mechanisms may be used in the nonextraction case, but the problems of space closure offer a particular challenge and therefore, the extraction case is very desirable in demonstrating the potentialities of segmental procedures.

This in no way implies that these procedures are primarily designed for the extraction case. It is the case analysis and treatment plan that determines extraction or nonextraction, not the particular appliance that an orthodontist may utilize.

Roughly speaking, arches may be classified into two groups, anchorage and nonanchorage, with the difference being the amount of displacement of posterior teeth that is allowable during the retraction of the anteriors. Anchorage arches may be of two types, the crowded arch with a marked arch length inadequacy from cuspid to cuspid and the noncrowded arch with no, or relatively little, arch length inadequacy from cuspid to cuspid. When considerable crowding exists in the anterior region, the treatment of choice is to first retract the cuspid by a tipping movement. The distal tipping of the crown is described as controlled tipping since an effort must be made to place the center of rotation at the apex of the cuspid. Following the full retraction of the cuspid, the axial inclination of the cuspid is corrected by distal retraction of the apex. As the cuspid is tipped posteriorly and perhaps as its axial inclination is corrected, the anteriors are banded and alignment initiated. In many cases when apical retraction has been completed on the cuspid, it will not be necessary to consider anterior retraction since forces distributed by transeptal fibers or lip pressure may have already retracted the anteriors. In other cases some anterior retraction or midline correction may be required.

The handling of the anchorage arch with an uncrowded anterior segment or a minimal arch length inadequacy from cuspid to cuspid is different. These arches usually require as much retraction of the incisors as of the cuspids. For this reason and because treatment is simplified, en masse retraction is used. In this type of case three major stages of treatment can be described. During the initial stage the anterior teeth and the posterior teeth are aligned and the deep overbite is corrected if present. The second stage is characterized by the en masse tipping of the six anterior teeth posteriorly with a center of rotation as the apex of the central incisor. During the third stage axial inclinations are corrected as en masse apical retraction of all six anteriors is accomplished. Fundamentally, it can be seen that anchorage is preserved in part by retraction in two phases, a tipping phase and an uprighting phase.

In the nonanchorage arches no attempt is made to tip teeth into the extraction site. The mechanics of treatment are simplified by bodily retraction (translation) of the anterior teeth. If the anterior segment is badly crowded, the cuspid is retracted bodily. If the anterior teeth have sufficient arch length from cuspid to cuspid, all six anterior teeth are translated posteriorly en masse.

The sections that follow describe the major mechanisms used in space closure; cuspid retraction, anterior retraction, apical retraction, and deep overbite correction. Little mention is made of the initial stage of treatment when rotations, buccolingual discrepancies, occlusogingival discrepancies, crossbites, and deep overbite are corrected. Certainly this initial stage of treatment may well be the most challenging since it is less subject to stereotyping than the later stages of treatment.

The Posterior Stabilizing Unit

In the first bicuspid extraction cases, the first molars, second bicuspids and, in many instances, the second molars are banded. The basic strap-up includes a tube on the second molar, a bracket on the first molar with an auxiliary

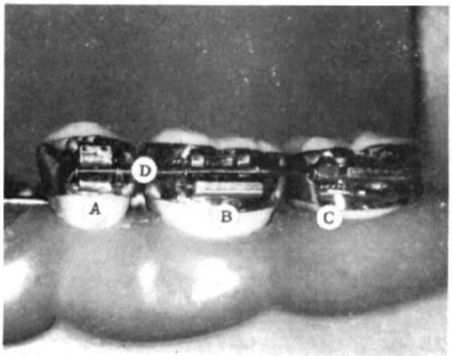
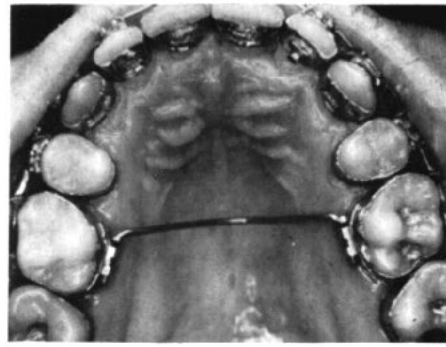


Fig. 1 Buccal Segment (A) Burstone bicuspid bracket. (B) Burstone molar bracket with auxiliary tube. (C) Tie-back washer. (D) Buccal stabilizing segment.

.022 × .028 tube, and a bracket-tube combination on the second bicuspid (Fig. 1). If a headgear is to be utilized during treatment, the bracket on the first molar will carry a .045 inch round tube.

Following the alignment of the posterior teeth a .0215 × .028 buccal stabilizing segment is placed. The segment is carefully made so that it will maintain the ideal relationship between the teeth in the posterior segments gained previously by less rigid wires. A washer which is placed one-half millimeter anterior to the buccal tube on the second molar serves as a tie-back or, if the second molar is not banded, the tie-back washer is placed one-half millimeter anterior to the bracket on the first molar. Since all future adjustments will be made through the auxiliary tube on the first molar, no inconvenience is found by having a bracket on this tooth. Furthermore, if later in treatment the second molar must be banded, a band change is not required on the first molar.

The linguals of the first molars have horizontal tubes for a removable lingual arch fabricated of .036 inch stainless steel. Usually, the maxillary arch will have a transpalatal lingual which



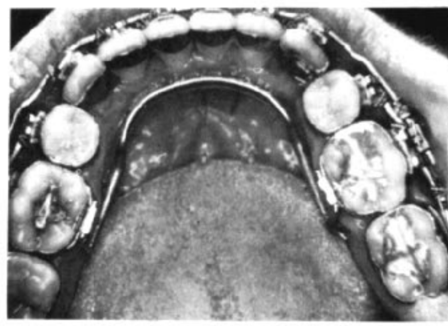


Fig. 2 Upper transpalatal lingual arch. Lower horseshoe lingual arch. The upper lingual is inserted from the anterior; the lower from the posterior.

is inserted from the anterior, although a horseshoe lingual may be indicated in some crossbite cases (Fig. 2). The mandibular lingual arch which inserts from the posterior is a low lingual with its anterior portion lying at the apical base region of the lower incisors. Both maxillary and mandibular linguals should be made one-half to one millimeter short of the tissue either at the depth of the palate or anteriorly in the incisor region. Alternate lingual attachments may include a bite plate or jackscrew for sutural expansion (Fig. 3). The lingual arch can be used for intersegmental movement or it can be placed passively as part of the posterior stabilizing unit.

Thus, the posterior stabilizing unit consists of rigid right and left buccal stabilizing segments connected by a lingual arch. If alignment has been

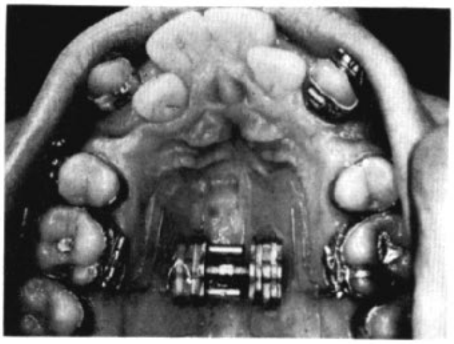


Fig. 3 Removable jack-screw appliance for sutural expansion. The buccal stabilizing segment is in place at this time.

properly accomplished, it should not be necessary to remove the buccal stabilizing segments until the completion of treatment. The posterior movements that will be accomplished from this point in treatment are accomplished as segmental movements of the entire posterior segment rather than individual tooth movements within the posterior segment. The posterior stabilizing unit could be thought of as composed not of six individual teeth, but rather as one large multirooted tooth encompassing the molars and premolars on both sides of the arch. The buccal stabilizing segments should be considered finishing arches since they will remain in place throughout treatment. The only modification that should be considered subsequently in the posterior segment might be between the right and left side on the upper and lower posterior segments. All future connections with the posterior stabilizing unit will be made from the auxiliary tube on the first molar or in a few instances from the tube on the second premolar.

A less satisfactory but acceptable method of placing the auxiliary tube is to solder it to the buccal stabilizing segment so that it will lie between the mesial and distal brackets on the first molar. At times it may be advantageous to use a wire of a smaller cross section than .022 × .028 for a stabilizing segment; however, as soon as possible a full size stabilizing arch should be placed for maximum rigidity.

Cuspid Retraction

Two major types of cuspid retraction may be attempted depending upon the anchorage required of the arch. If minimal displacement is required of the posterior segment, two phases of cuspid retraction are recommended. The first phase is characterized by a tipping of the crown of the cuspid with the center of rotation at the apex. In the second stage the apex of the cuspid is retracted with the center of rotation approximating the bracket of the tooth. In other cases where anchorage is not so critical, translation (bodily movement) of the cuspid is indicated. The following mechanism is used in the first phase of retraction during which the cuspid is tipped posteriorly.

The cuspid retraction mechanism consists of two basic parts: (1) the posterior stabilizing unit and (2) the cuspid retraction assembly (Fig. 4). The posterior stabilizing unit has been previously described and once it is in place cuspid retraction can be initiated. The cuspid retraction assembly consists of a retraction spring, base arch, adjustment washers and tie-back loop.

The spring is fabricated of .010 × .020 wire. Anteriorly the wire is laminated so the spring will orient into the cuspid bracket. Posteriorly the spring is attached to the base arch by a rectangular washer. Spring height (measured gingivally to the level of the bracket) is either four or six millimeters. The longer spring is preferable since its load-deflection characteristics are much lower and for that reason should be used whenever feasible. The .021 × .025 base arch connects the spring with the auxiliary tube on the bracket of the first molar.

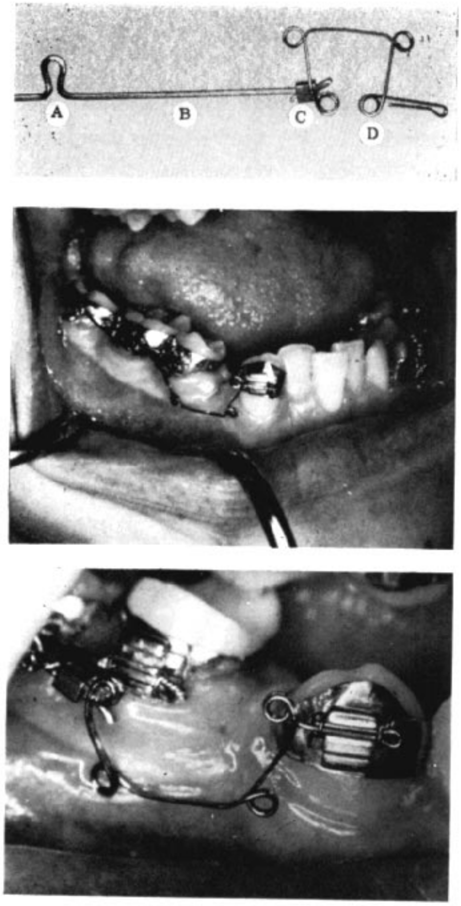


Fig. 4 Top, cuspid retraction assembly. (A) Tie-back loop. (B) Base arch. (C) Adjustment washer. (D) Spring. Middle, overall view of assembly following activation. Bottom, close-up of spring as it attaches to the cuspid bracket and the base arch.

Controlled cuspid retraction requires the placement of both forces and moments at the bracket of the cuspid. Thus, a frictionless mechanism implies that the necessary forces and moments must be incorporated into the spring mechanism itself. Four major activations must be considered in relation to the cuspid: the distal force, the antirotation moment, antitip moment and intrusive force.

A typical activation of the six mm spring would be two hundred grams which is approximately seven millimeters of activation. On the average the force is dissipated approximately 25 grams for every millimeter of tooth movement. After the cuspid has been retracted three millimeters, the spring should be reactivated to a full seven millimeters by sliding the adjustment washer posteriorly on the base arch. The adjustment washer can be crimped at this point or the base arch can be bent occlusally at its mesial end to act as a stop after the excess length of the base arch has been cut off. Although it is possible to fully retract a cuspid with a nine millimeter activation of the spring, two activations of seven millimeters are recommended in order to maintain a more constant force level. The load-deflection characteristics of the six and four millimeter springs are given in Figure 5.

It is apparent that with the distal

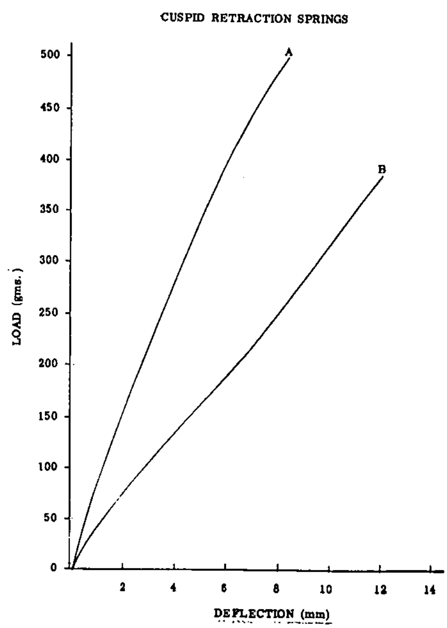


Fig. 5 Load-deflection graph for cuspid retraction springs. A. 6 mm. B. 4 mm. Note that the taller 6 mm spring has the lower deflection rate.

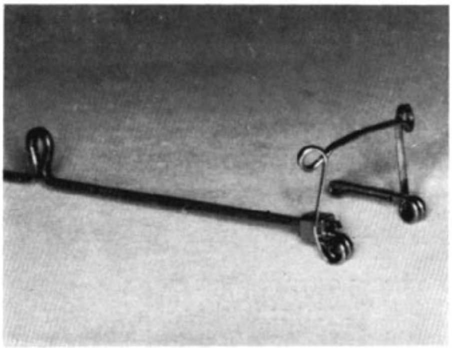


Fig. 6 Cuspid retraction spring showing a 180° antirotation twist. Without this antirotation moment the cuspid would rotate during retraction.

force alone the cuspid root would displace forward during the retraction of the crown. For this reason an antitip moment must be available during retraction. Since the anterior and posterior portions of the assembly are restrained by the auxiliary tube and the bracket of the cuspid, during distal activation of the assembly an antitip moment is delivered automatically to the cuspid. Additional bends are placed at all four helices to further enhance the antitip characteristics of the spring. In other words, the highest possible moment available in the spring is to be utilized to control the root apex. A more complete description of the placement of antitip bends will be discussed again under anterior retraction.

Since a distal force on the bracket of the cuspid would rotate the cuspid with the distal toward the lingual, it is necessary to place an antirotation moment in the spring. This is accomplished by having the spring twisted in a direction so that in the process of tying it into the bracket the proper moment is created (Fig. 6). Typically 160 to 180 degrees of antirotation moment is placed in the spring itself.

The last major activation that should be mentioned is the intrusive force that is placed on the cuspid. An intrusive bend or tip-back bend is placed at the tie-back loop on the base arch. The primary purpose of this bend is to prevent the posterior segments from tipping forward into the extraction site. Reciprocally, of course, it has the effect of intruding the cuspid. It should be further pointed out that the base arch should be contoured so it is barely touching the bicuspid bracket. In this way the proper width of the cuspid will be maintained during retraction.

Thus, during cuspid retraction controlled tooth movement is produced by incorporating all the necessary forces and moments into the assembly itself rather than allowing the tooth to slide distally along the archwire. This is very important since it eliminates the friction which is inherent in any sliding mechanism. Friction becomes particularly significant in the sliding of a bracket along an archwire since the crown of the tooth is far occlusal to the center of resistance of the root. Basically then we are dealing with a frictionless mechanism provided some of the internal friction within the spring is disregarded.

A simple way to insert the cuspid assembly is to initially place a cotton roll in the mucobuccal fold. The base arch is placed into the auxiliary tube and tied back. The spring can then be twisted forward into the bracket on the cuspid. The spring should be carefully checked to make sure that it irritates neither the cheek nor the gingiva. Since the assembly is rigidly attached at both ends, it is possible to torque the spring either buccally or lingually for maximal comfort and have this orientation remain in place during cuspid retraction.

The response to the cuspid retraction mechanism is variable. In many patients cuspid retraction can be completed in six weeks; in some adults retraction may take longer than four months. Typically, in most patients, the

Fig. 7 Left, upper cuspid root spring. Lower .015 x .018 retraction assembly. Right, upper cuspid root spring with an anterior segment.

cuspid will be retracted the full distance of the extraction site within twelve weeks. Very little forward displacement of the anchorage unit can be noticed during this stage of treatment. If cervical or occipital headgears are used to reinforce the posterior stabilizing unit, some retraction of the posterior teeth may be accomplished simultaneously with cuspid retraction.

Apical Retraction of the Cuspid

The force system that is utilized for cuspid apical retraction can be very simple if a single force is placed apically to the center of resistance. If properly positioned, the single force acting on the root could retract the root apex of the cuspid without displacing the crown forward. Since it would entail a rather cumbersome appliance to deliver a force on the root of the tooth, it is far more practical to replace the single force with an equivalent force system acting at the bracket. It can be seen that a force and a couple or moment acting at the bracket would be capable of producing distal root movement provided that a proper ratio existed between moment and force. The ability to deliver the proper magnitude or force and moment is a requirement of any well-designed cuspid root spring.

The mechanism that is used for cuspid root movement consists of two parts: (1) the anchorage unit, and (2) a cuspid root spring.

The cuspid spring is made of 18-8 stainless steel with a cross section of .018 $\times$ .025 (Fig. 7). Two helices are incorporated into the wire; one is mesial to the cuspid bracket, and the other mesial to the auxiliary tube. In identifying a right from a left spring it should be noted that the helices are wound out toward the buccal as one looks from the anterior to the posterior.

The spring has been designed to deliver relatively constant force over a long range of action. To achieve this end it is necessary to develop a low torque-twist rate in the root spring.

By definition, the torque-twist rate refers to the torque per unit activation. It is measured in gm-mm/per degree, i.e., the amount of moment produced for each additional degree of activation. It should be remembered that with a low torque-twist rate it is necessary to activate the spring a great number of degrees, perhaps as high as 180°, to build up to the desired moment. Since such a high angular deflection is required, it can be readily seen that as the cuspid root moves posteriorly the force values will not be radically reduced. In this way a more constant level of torque is maintained on the cuspid throughout the entire stage of root movement.

We might now consider the various features that have gone into the design of the root spring to create a low torque-twist rate. Not only must the spring have a low torque-twist rate, but also it must be able to deliver an optimal moment without permanent deformation. We will now see why it is possible to place 180° or more of activation in a member of this type without permanent deformation.

It can be seen that the perpendicular distance between the auxiliary tube and the bracket on the cuspid is considerably greater than the perpendicular distance normally found between two brackets. If cuspid root movement was attempted in a continuous arch between the bicuspid and cuspid brackets, the limited amount of space would raise sharply the torque-twist rate and would reduce the effectiveness of the spring. If typical distances between the auxiliary tube and cuspid bracket (20 mm) and between the bicuspid and the cuspid brackets (5 mm) are compared the ratio of the distances is 4 to 1. With this type of loading the torque-twist rate will vary inversely as the second power of the length and, hence, increasing the distance by a factor of three will reduce the torque-twist rate by a factor of sixteen.

The placement of two helices further reduces the torque-twist rate. The amount of reduction depends upon the size of the helices and the number of turns per helix. With a typical cuspid root spring the effect of adding the helices is to reduce the torque-twist rate about one-fourth.

If we add the total effect of increased distance between points of force application and the placement of helices, we will find that the torque-twist rate has been reduced by a factor of sixty-four in comparison with using a plain wire of the same cross section directly connecting the cuspid and bicuspid brackets. This remarkable reduction in torque-twist rate is responsible for the large angular deflection that is necessary to maintain a relatively constant moment on the cuspid. It is thus assured that, as the spring deactivates in the mouth, the amount of torque will not radically change for each millimeter of apical movement that is produced.

The cuspid root spring is fabricated in the following manner. Working from the anterior portion of the wire the operator should incorporate a helix with two and one-half turns mesial to the bracket of the cuspid. A second helix with one and one-half turns is placed immediately in front of the auxiliary tube on the buccal stabilizing segment. The desired preactivation is incorporated into the anterior helix; however, the wire distal to the posterior helix lies horizontal until all contouring is completed.

A typical cuspid root spring is bent so that two equal and opposite moments or couples are delivered during activation, one to the cuspid and the other to the posterior segment. If the bracket of the cuspid is parallel to the auxiliary tube, the anterior and poste-

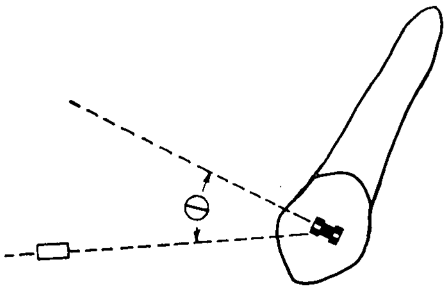


Fig. 8 Angle Θ is the angle formed between the occlusal plane and the long axis of the bracket.

rior arms of the root spring should cross equally the auxiliary tube and cuspid bracket. The geometry of the situation would assure the delivery of equal and opposite couples. However, following cuspid retraction, the bracket is not parallel with the tube because the cuspid has tipped during its retraction. To assure the production of equal and opposite couples to the anterior and posterior segments, it is necessary to subtract the angle of tipping (Θ) from the activation of the anterior arm (Fig. 8). For example, if there were no tipping we might activate the anterior arm 90 degrees and the posterior arm 90 degrees to the tube and bracket respectively. If the cuspid, on the other hand, is tipped 30 degrees then the

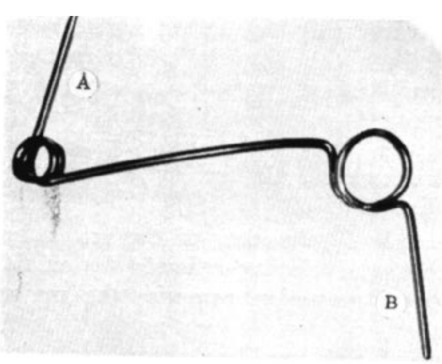


Fig. 9 A typical cuspid root spring before placement in the mouth. Note that the posterior arm (B) is bent more than the anterior arm (A).

posterior arm would still be activated 90 degrees, but 30 degrees would be subtracted from the 90 degrees of activation on the anterior arm leaving 60 degrees. Thus, a 60 degree anterior preactivation and a 90 degree posterior preactivation would deliver a pure moment or couple to the cuspid. It should be noted that in placing posterior preactivation the wire is bent at the junction of the helix and middle horizontal portion of the spring (Fig. 9).

There are a number of other possible activations where equal and opposite couples are not delivered respectively to the cuspid and to the posterior segment. Disregard for the present the angulation of the bracket. If one were to place more activation in the posterior arm of the spring than the anterior, not only would the cuspid root move back, but also the cuspid would tend to depress. On the other hand, if one increases the activation in the anterior arm relative to the posterior arm, the cuspid tends to elevate. In both of these instances there will be root movement of the cuspid as well.

A reciprocal force and moment act on the posterior segment which tends to displace anchorage during cuspid root movement. In order to minimize this tendency a moment of 3,500 gram/millimeters or less should be used for cuspid apical retraction. Moments higher than 3,500 gram/millimeters, although they might be more efficient for apical movements, may displace posterior segments forward unless a headgear or some other distal force is used.

The force system just discussed refers only to the initial set of moments that are delivered when a cuspid root spring is placed. As the cuspid axial inclination tends to correct itself, there is a change in force system. For all practical purposes this is not too significant. It should be remembered, however, that as the cuspid root improves, the tendency of the spring will be to depress the cuspid slightly. If a second activation is deemed necessary, and usually this is not the case, it then may be necessary to increase the activation in the anterior arm.

The horizontal activation of the cuspid retraction spring is also important since it determines the intercuspid width. The spring can also be utilized to rotate a cuspid simultaneously with cuspid apical retraction. It is recommended, however, that major rotations be corrected before beginning the stage of cuspid root movement. The springs should be contoured so that the anterior portion of the spring will be two millimeters lingual to the cuspid tip cusp. The anterior arm is rotated about 30 degrees in a direction tending to rotate the cuspid with its distal toward the buccal. The importance of the horizontal bends should be reemphasized since a common error is to place a straight spring with no or improper contour into the cuspid bracket. A spring without proper contouring for the cuspid would naturally bring the cuspid buccal and thereby increase intercuspid width. If the distal of the cuspid is slightly rotated with the distal toward the lingual, the lingual contouring at the mesial helix can be accentuated. It is necessary, if an attempt is being made to rotate the cuspid, to further increase the constriction in the spring so that a definite lingual force is present on the canine.

The last activation that should be mentioned is lingual root torque. When a cuspid is retracted into the canine fossa, the root may become prominent if it is not moved lingually at the same time. For that reason, it is desirable to place some lingual root torque in a cuspid spring, preferably of a .0215 $\times$ .028 cross section. If lingual root torque is placed, an additional constrictive force should be placed in the root spring to prevent the buccal displacement of the cuspid crown. Since an .018 $\times$ .025 wire lacks positive orientation in a .022 $\times$ .028 slot or tube, small bends or "waves" can be placed in the anterior and posterior arms to assure orientation.

Let us now summarize the steps needed to prepare a cuspid root spring for placement in the mouth: (1) proper width and contour is placed in the horizontal plane, (2) lingual root torque is placed if required, (3) the second order activations are made so that the proper moment and vertical forces are delivered to the cuspid, and (4) the spring is then stress relieved.

Before placing the cuspid root spring in the mouth it is necessary to tie back the cuspid to the bicuspid with a "rope" tie. By twisting a piece of .007 ligature wire to form a rope a definite tie back on the cuspid is produced. It should be remembered that, without a tie back, the application of a moment will produce forward displacement of the cuspid and reopening of the extraction site. The tie should be made carefully so that there is no slack along the length of the ligature wire.

Before inserting the cuspid root spring a cotton roll is placed in the mucobuccal fold. The spring is inserted initially into the auxiliary tube on the first molar and is allowed to rest anteriorly in the cotton roll. The anterior arm is then twisted into the bracket or tube on the cuspid. If the tube on the cuspid is used, the spring is inserted simultaneously in both tubes with two pliers.

Cuspid retraction of the crown by controlled tipping followed by cuspid apical retraction comprise the major treatment steps in treating the Class I arch-length problem where posterior segments cannot be markedly displaced forward. A case treated in this manner is shown in Figure 10.

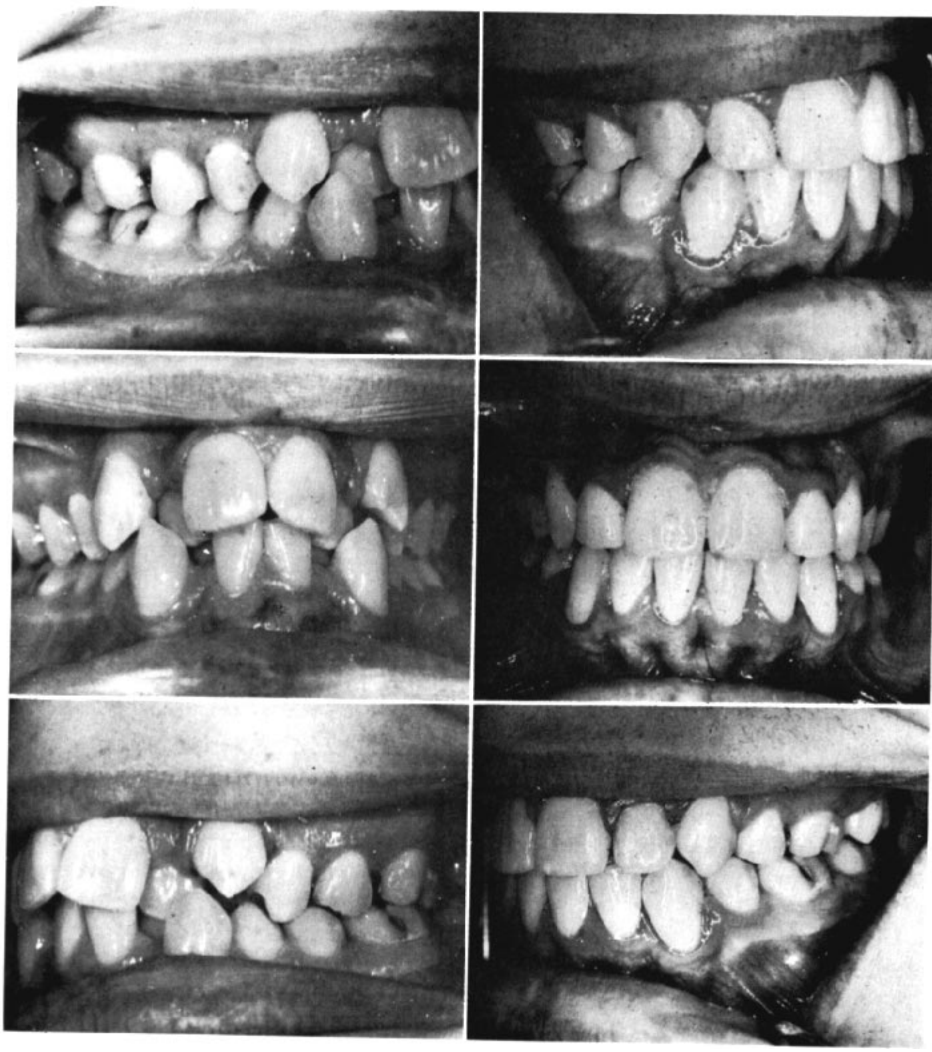


Fig. 10 A Class I arch length inadequacy treated by separate stages of cuspid tipping and apical root retraction.

Anterior Retraction

The anterior retraction mechanism can be used both for retraction of the four anteriors as well as midline correction. If the preceding step in treatment were cuspid apical retraction, the cuspid can now be joined to the posterior segment by a short .0215 ×.028 extension from the auxiliary tube on the bicuspid bracket to the bracket on the cuspid. In this way the cuspid becomes integrated into the posterior stabilizing unit.

The anterior retraction assembly consists of three portions: (1) an anterior segment, (2) right and left anterior retraction springs, and (3) right and left base arches (Fig. 11). The .0215 × .028 anterior segment is ideally contoured to the anterior teeth which may include the placement of lateral insets and differential torque. The two washers which attach the spring to the anterior segment are movable and are slid along the anterior segment so that they touch the distal of the lateral brackets and are crimped in place in this position. The excess wire lying distal to the tubes is removed.

The springs used for anterior retraction are fabricated of .010 × .020 wire. Two hundred grams of force are used for the retraction of a maxillary central and lateral and about one-half that amount for a mandibular central and lateral. The load deflection charac-

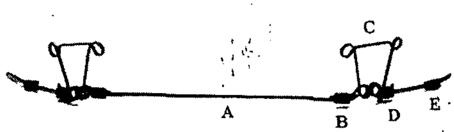


Fig. 11 Anterior retraction assembly (A) Anterior segment. (B) Anterior adjustment washer. (C) Spring. (D) Adjustment washer on the base arch. (E) Tie-back washer.

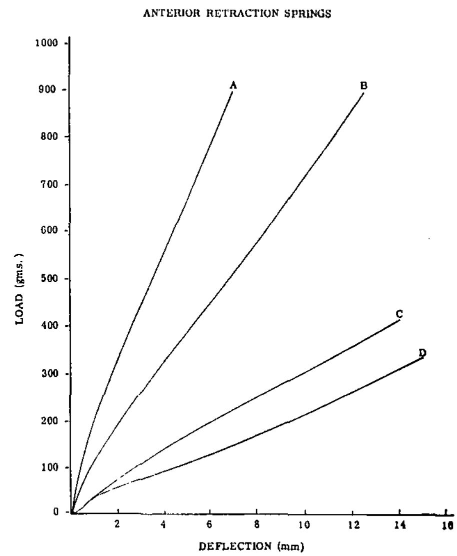


Fig. 12 Load-deflection graph for anterior retraction spring. A. .015 x .028 (6 mm) B. .015 x .028 (8 mm) C. .010 x .020 (6 mm) D. .010 x .020 (8 mm)

teristics of the eight and six millimeter anterior retraction springs are given in Figure 12. It can be seen that approximately twelve millimeters of activation are required in the eight millimeter length spring to deliver two hundred grams of force for maxillary retraction. In the neutral or passive position the proximal surfaces of the occlusal helices lightly touch each other. Hence, with a twelve millimeter activation they would lie twelve millimeters apart. The length of the spring, either eight or six millimeters, is determined by the depth of the mucobuccal fold. Ideally, the more favorable load deflection characteristics of the eight millimeter spring would suggest its universal usage. Usually, however, the mucobuccal fold depth in the mandibular arch dictates the employment of the shorter six millimeter spring.

If the lingual activation alone were placed in the anterior retraction spring, rapid retraction would no doubt occur, but lack of control would be evident in

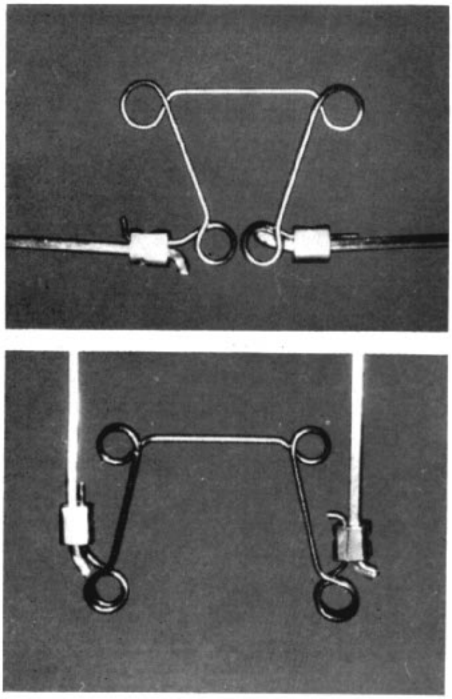


Fig. 13 Anterior retraction spring above, before placing the torque. Below, after placing 180° of torque.

maintaining the root apices in their original positions. It is therefore necessary to create a moment from the spring itself which prevents the apices from being displaced forward. This moment reads as lingual root torque in the anterior brackets. The moment is produced by placing a 45 degree bend at each occlusal helix and by winding the gingival helix an additional 45 degrees. The bends or winds are always made in a direction to enhance the amount of lingual root torque in the anterior segment (Fig. 13). If properly placed, the assembly will now have approximately 180 degrees of torque. It can be seen that in a mechanism of this type, not only does the lingual force remain relatively constant during retraction, but also the torque or moment values will change little since such large deflections of the spring are utilized for their production.

The .021 × .025 base archwire has two washers. The anterior washer which attaches to the .010 × .020 spring is usually not crimped so that future activations can be made by sliding the washer posteriorly on the base wire. In this way it is not necessary to remove the assembly from the mouth. Since the posterior portion of the base archwire is inserted into the auxiliary tube, the posterior washer serves either as an initial means of adjustment for lingual activation or as a means of tying back the anterior retraction assembly. As in the cuspid retraction mechanism an intrusive or tip-back bend is placed in the area of the posterior washer in order that the posterior teeth will not tip into the extraction site.

Movement of the four anterior teeth can be accomplished quite rapidly. Usually one activation of the assembly is adequate. Additional reactivations are not only time consuming and unnecessary, but may well be detrimental to the rate of tooth movement and the pain threshold. If a midline asymmetry is present, the assembly is fully activated on the side to which the midline is to be moved and approximately one-half the normal activation on the opposite side.

The simplest procedure for placing the assembly is to first tie the anterior segment into place leaving the base archwires outside the mouth. The base archwires are then placed in the auxiliary tubes of the first molars and securely tied. Special care should be given to the placement of the springs so they neither impinge on the gingiva or project into the cheek.

The assembly which has just been described is used for controlled tipping movements on the four anterior teeth. If translation or bodily movement is indicated, a similar assembly with a .015 × .028 spring should be utilized.

Since heavier forces must be used for efficient translation, these assemblies do not conserve anchorage as their lighter .010 × .020 counterparts.

If no arch-length inadequacy is present in the anterior segment, or if crowding is minimal, it is simple to retract all six anterior teeth as a unit rather than to go through separate stages of cuspid and anterior retraction. En masse tipping followed by en masse root movement is resorted to in cases where posterior segments cannot be allowed to displace forward. On the other hand, if displacement of posterior segments up to one-half of the extraction site is in agreement with the treatment plan, a single step of en masse translation of all six teeth can be attempted. No matter what type of en masse anterior retraction is used, all six anterior teeth are handled as a rigid unit. In analyzing the posterior anchorage unit we pretend that all of the posterior teeth are one large multirooted tooth. In a similar manner, by rigidly connecting all six anterior teeth, one can treat the anterior segment as if only one large multirooted tooth were present which, among other advantages, considerably simplifies the mechanics of space closure.

Early in treatment, following the alignment of the anterior teeth, a heavy edgewise anterior segment is placed. The cross section of this segment should be at least .021 × .025. It is ideally contoured in all three planes of space to finish the detailed alignment of the anterior teeth. If properly formed it should not be necessary to remove the anterior segment until the completion of treatment. Vertical .022 × .028 tubes are soldered between the cuspid and the lateral brackets. Assemblies that are to be used for either en masse tipping, translation, or root springs are attached to the anterior segment at these auxiliary vertical tubes. No future adjustments need be planned in the anterior segment itself since the anterior teeth will be treated as a unit.

In principle the assemblies to be used for en masse retraction are very similar to those previously described for anterior retraction of the four incisors. The major difference is that in the case of en masse retraction no anterior segment is incorporated in the assembly since the anterior segment is placed early in treatment and remains in place during all subsequent stages. The assemblies, therefore, are nothing more than left and right sections which attach at the auxiliary tube on the buccal stabilizing segment and the auxiliary vertical tube on the anterior segment (Fig. 14).

The assemblies for en masse anterior retraction consist of a retraction spring and a base archwire. The retraction spring is fabricated either of .010 × .020 or .015 × .028 wire depending upon the need for tipping or translation. Eight millimeter and six millimeter length springs are utilized depending upon the depth of the mucobuccal fold. The base archwires hold two washers, the anterior which is an adjustment washer and the posterior which is used as a tie-back.

The various activations of the en masse retraction assemblies are very similar to the anterior retraction assembly. For example, with the eight millimeter spring usually fourteen millimeters of activation is used for en masse tipping (.010 × .020 wire) and eight millimeters of activation for translation (.015 × .028 wire). The anterior washer on the base archwire can be used for future activations if required. Antitip bends are placed in the spring as well as a tip-back bend at the posterior of the base archwire.

After en masse tipping of all six anteriors has been completed it is necessary to follow this stage of treatment in most instances with en masse apical retrac-

Fig. 14 En masse retraction assembly. Top, prefabricated assembly. Middle, assembly activated in mouth. Bottom, the spring is attached to the vertical tube on the anterior segment.

tion. The rationale is to retract all six roots as a unit rather than to move individually the apices of the anterior teeth. It is possible in some cases that the incisor roots do not have to be retracted as far as the cuspids. In these situations the anterior segment is rounded in the incisor brackets. Figure 15 shows an en masse root spring fabricated of .018 × .025 wire. In principle,

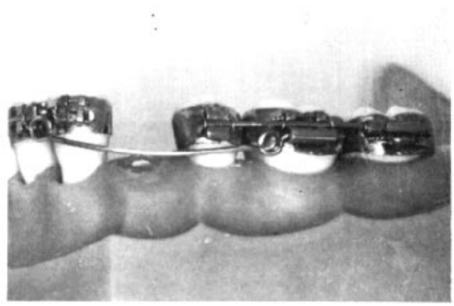


Fig. 15 En masse root spring for apical retraction of the six anterior teeth.

the en masse root spring is handled very similarly to the cuspid root spring previously described. A case treated by en masse translation of both the lower and upper anterior segments is shown in Figure 16. Figure 17 illustrates the two stages of en masse tipping and en masse apical retraction in the mandibular arch.

Apical Retraction of the Incisors

There are many situations that require the apical retraction of the incisors. The classic example is the Class II, Division 2 case where the roots of the central incisors must be retracted. In protrusive cases it is also possible that, following anterior retraction by tipping, apical retraction may be indicated. In any event it cannot be emphasized too strongly that the amount of root retraction can be minimized by employing mechanics that do not displace the roots forward during anterior retraction.

The mechanism used for apical retraction of the incisors consists of three components: (1) The anchorage unit previously discussed, (2) the anterior segment, and (3) an incisor root spring (Fig. 18).

The anterior segment is nothing more than a .021 × .025 continuous archwire which is inserted into the tube on the bicuspid. The anterior segment

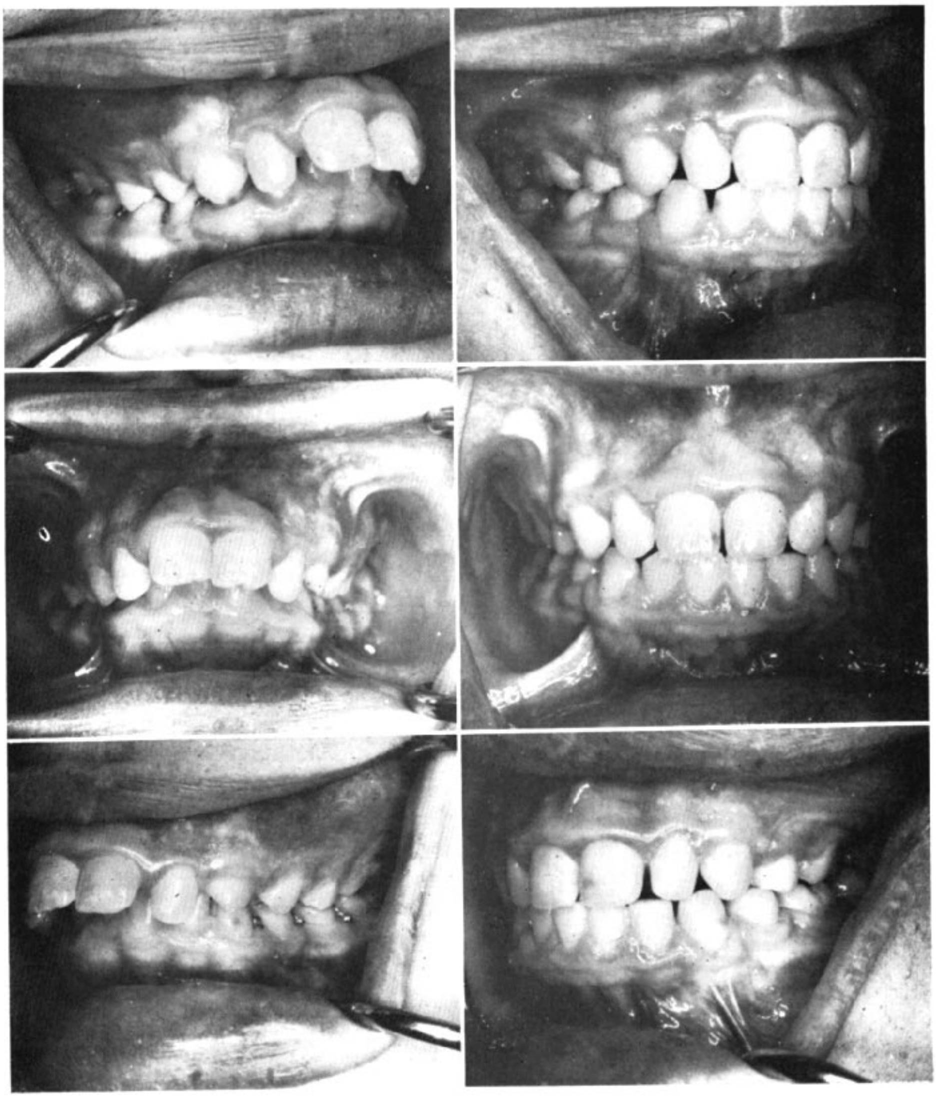


Fig. 16 Class II, Division 1 case with deep overbite treated by en masse translation in both arches. Headgear was used in the upper arch.

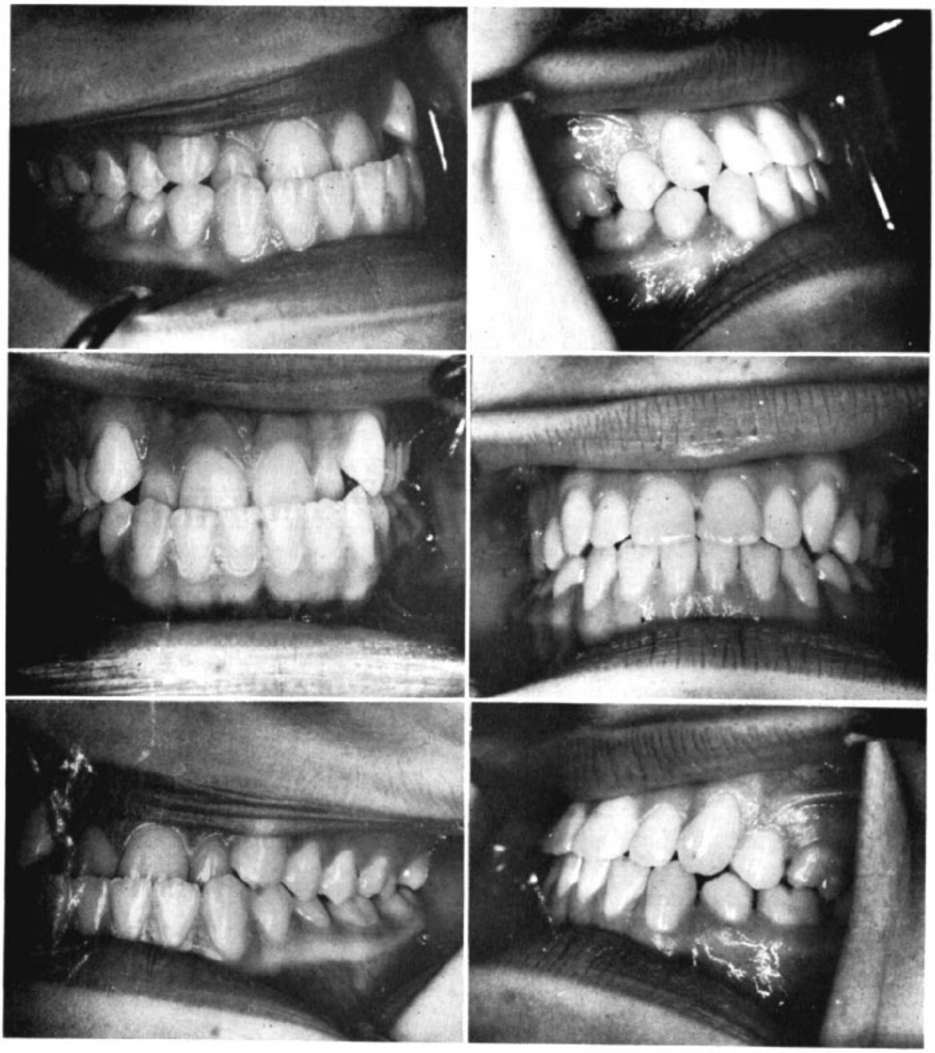


Fig. 17 Class III case treated by two stage en masse retraction in the lower arch (en masse tipping followed by en masse root movement).

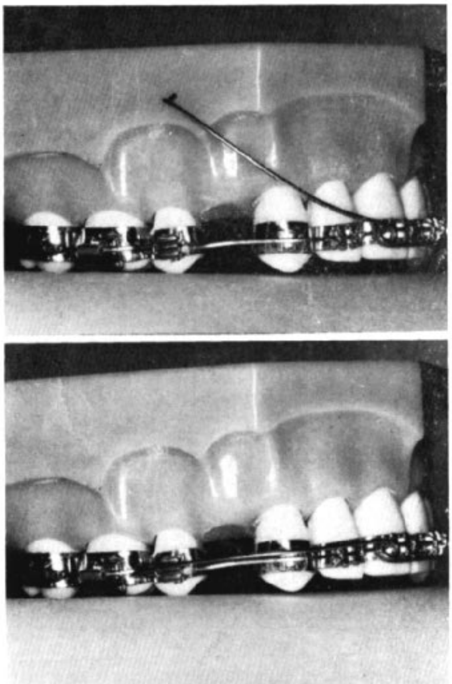


Fig. 18 Anterior root spring. Above, passive position. Below, active position.

is fitted into all anterior brackets except those on the teeth to be torqued. If the two central incisors are to be torqued lingually, the anterior segment is stepped incisally approximately one-half millimeter at the mesial of the lateral bracket and is contoured so that it will lie against the band surface on the central incisors and against the occlusal wing of the incisor bracket. If four anterior teeth are to be torqued lingually, the anterior segment dips incisally beginning at the mesial of the cuspid bracket. Washers which are placed one millimeter forward to the bicuspid tube serve as tie backs to prevent any flaring of the incisors.

The root spring is fabricated of .0215 × .028 wire. Immediately distal to the bracket of the most posterior tooth to be torqued, a helix is bent toward the occlusal; the wire continues posteriorly and between the first molar and second bicuspid brackets a hook is bent.

The major steps in placing the root retraction mechanism are described below. The anterior segment is first tied into place. It is important to tie back firmly the anterior segment to prevent any flaring of the maxillary incisors. A preactivation bend and twist is placed in the root spring so that the hook will lie toward the gingiva. The spring is then tied into the anterior brackets and the posterior arm is hooked on the buccal stabilizing segment. For central incisor root movement 2,000 gram/millimeters is used per side and for central and lateral root movement 3,000 gram/millimeters per side. With typical distances this means that from 75 to 150 grams of force would be required to deflect the ends of the torquing spring down to the level of the buccal stabilizing segment.

It should be remembered that, although higher activations of the root spring may produce greater tooth movement in a given interval of time, the higher moments produced may also displace the posterior segments forward and may add to the danger of root resorption on the anterior teeth.

The Correction of Deep Overbite

The mechanism for the correction of deep overbite consists of three parts: (1) the posterior stabilizing unit, (2)

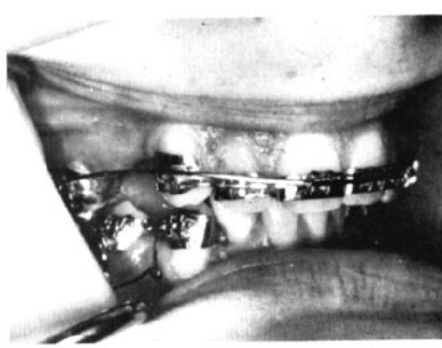


Fig. 19 Base arch (depressive arch) used for deep overbite correction. The arch lies labial to the anterior segment.

the base or depressive archwire and (3) the anterior segment (Fig. 19).

The base arch is fabricated of .021 × .025 wire. Two washers are placed on the wire one millimeter anterior to the auxiliary tube on the first molar. By placing a depressive bend on either side at this washer it can be readily seen that a force would be exerted tending to intrude the anteriors if the base archwire were tied to the anterior segment in the midline.

Among other effects, the action of the base archwire is to extrude posterior teeth as well as to intrude the anteriors.[8] The amount of relative extrusion or intrusion can be influenced by a number of factors. The lower the force delivered from the base archwire, the greater will be the anterior intrusion in comparison with posterior extrusion. Furthermore, if genuine intrusion of the incisors is indicated, it is far better to limit the number of teeth in the anterior segment. For example, attempts to intrude all six anterior teeth as a unit are not as effective as the intrusion of two or four incisors alone. Lastly, the vertical anchorage of the posterior teeth can be enhanced with the use of an occipital gear.

Activation of the base archwire produces moments that tend to steepen the plane of occlusion in the maxillary arch and to flatten it in the mandibular arch. Since the steepening of the plane of occlusion of the maxillary arch is particularly undesirable in many cases, it is necessary to negate the moment produced from the base wire. This negation can be produced either by the use of a cervical gear with the outer bow high or an occipital gear with the force placed anterior to the center of resistance of the posterior segment.

Retraction of Posterior Teeth

A number of methods can be used to retract posterior teeth including the use of Class II and III elastics and direct headgear traction. A tip-back mechanism will now be described which is used in those situations where a marked curve of spee exists in the lower arch and where the treatment plan will call for flattening the plane of occlusion of this arch.

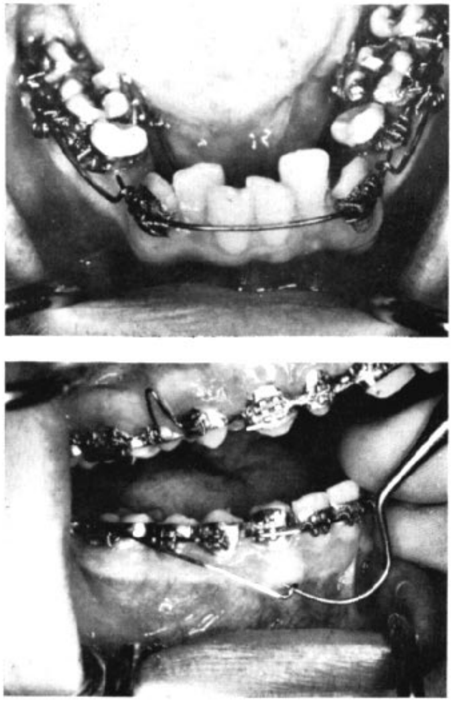


Fig. 20 Tip back assemblies. Above, with only cuspid banded. Below, with all six anteriors banded. The posterior teeth are being tipped back and the curve of spee removed.

The tip-back mechanism consists of (1) the posterior stabilizing unit, (2) the anterior segment and (3) right and left tip-back springs (Fig. 20).

The anterior segment will vary depending upon the needs of the case. If the anteriors are badly crowded and cuspid retraction is planned, the anterior segment consists of a .021 × .025 wire connecting the cuspids and projecting approximately three millimeters posterior to the cuspid bracket. The anterior teeth are not banded at this stage. If little or no crowding is present, all six anterior teeth are banded and a .021 × .025 wire is contoured passively into their brackets.

The retraction spring is fabricated of .018 × .025 wire. Immediately mesial to the auxiliary tube of the first molar a helix is wound (1¾ turns) ; a hook is formed distal to the cuspid bracket in situations where only the cuspids are banded and between the cuspids and lateral bracket when all of the anterior teeth are banded. The hook should be free to slide along the archwire as posterior teeth are tipped back. It should be noticed that an attempt is made to place the hook near the center of resistance of the anterior segment so that neither protrusion nor retrusion of the anteriors occurs as an undesirable side effect. To eliminate play in the auxiliary tube the posterior part of the spring can be curved slightly to take up any slack tube. If a tip-back bend is placed at the posterior helix, it can be readily seen that, during activation, when the hook is brought up to the level of the anterior segment, a moment is produced which will tend to tip the posterior teeth back and elevate the bicuspids. This particular mechanism is efficient in tipping back the posterior teeth, flattening the occlusal plane, and correcting deep overbite.

Discussion

The segmented arch technique has been developed with three primary objectives: (1) force control over active and reactive teeth, (2) reduction in the number of chair hours required to treat a case, and (3) minimization of patient cooperation.

Force control implies not only control over the centers of rotation of teeth, but also an optimal tissue response. From a mechanical point of view a number of factors have been considered in the segmented arch technique to achieve this end. Ideal springs must produce the proper moment to force ratio to control the center of rotation of the tooth being moved and the moment to force ratio must be delivered constantly at a proper or optimal level. Furthermore, an appliance should be relatively frictionless so that force is not lost through bending of wire and bracket; the range of action of the spring should be large and the delivered force systems be measurable or known. In short, the springs used in the segmented arch technique deliver known moments and forces at a relatively constant level with minimal friction.

Two considerations for designing resilient orthodontic springs are relatively low load-deflection rates and freedom from permanent deformation. In order to meet these objectives a number of engineering principles have been applied to the design of retraction springs. To illustrate the engineering principles let us use as an example the design of an anterior retraction spring.

The anterior retraction spring is fabricated of 18-8 stainless steel wire. It could also be fabricated of gold alloy; however, the cross section of the spring would have to be greater if the spring properties remain the same. Since it is desirable to have a spring which has the lowest possible load-deflection rate and which does not easily deform, two mechanical properties must be considered: elastic limit (or yield point) and modulus of elasticity. Ideally a high elastic limit and a low modulus of elasticity is required. Since the ratio between elastic limit and modulus of elasticity may be slightly higher in a small cross section of stainless steel, a stainless steel alloy which has been work-hardened to a point of high temper will have a small advantage in spring properties over the typical gold wire. Nevertheless, it should be pointed out that springs with adequate properties could be made in gold.

The anterior retraction spring has

been formed of flat wire because flat wire is the optimal cross section for undirectional bending. More energy can be absorbed in a cross section of this size than any other cross section available. The smallest possible cross section is used consistent with the force and moment requirements of the spring. Since increasing the height and length of the spring reduces the load-deflection rate without proportionately reducing the maximal load of the spring, added vertical and horizontal extensions of wire are employed. Helices, which are bent to take advantage of residual stress, have also been strategically incorporated in areas of maximal stress. To further enhance the ability of the spring to withstand permanent deformation, the springs are stress relieved. By applying all of these principles the load-deflection rate is significantly reduced and the chance of permanent deformation is minimized.

With the possibility of accurately measuring the forces and moments delivered to teeth during orthodontic therapy, not only is it possible to improve the quality of orthodontic treatment, but it is also possible to learn about the nature of optimal forces that are needed clinically. As orthodontists compare results in terms of pain, rate of tooth movement, tooth mobility, root resorption and anchorage control, and correlate these with the force systems incorporated in treatment, the nature of optimal force systems will become more evident. The uniformity of prefabricated springs allows calibration in the laboratory and hence, data charts can be constructed which simplify the determination of the forces delivered clinically.

Anchorage is controlled in part by distributing the reactive forces to those teeth that are best able to withstand displacement. In typical continuous arch mechanics the anchor teeth are usually adjacent to the ones that are being moved since forces are distributed from bracket to bracket. By segmental procedures it is possible to distribute forces around the arch to take advantage of either reciprocal anchorage or of anchor teeth that are more resistant to displacement. Moreover, rigid wires can be used to enhance the anchorage potential of a group of teeth as demonstrated by the posterior stabilizing unit.

In the segmented arch technique chair time can be reduced during treatment because only isolated sections of archwire need be removed and activated during each stage of treatment. Furthermore, few adjustments are needed since constant force springs have a long range of action.

Summary

Some of the principles and applications of the segmented arch technique have been discussed. The technique is designed to deliver relatively constant-optimal forces with the aim of full control over those teeth that are to be moved as well as the anchor unit. Specialized springs have been described which can be used for either individual or en masse tooth movement.

Controlled tipping followed by apical retraction is used on those extraction cases where little displacement of posterior segments is allowable. On the other hand, translation is attempted in those cases where posterior segments can be protracted at least one-half of the extraction site during space closure.

En masse movement of all six anterior teeth is accomplished whenever possible. In particular, in those situations where the anterior teeth are reasonably well-aligned all six anteriors are retracted as a unit rather than resorting to separate steps of cuspid and anterior retraction.

A number of mechanisms have been described for cuspid retraction, anterior retraction, apical retraction, deep

overbite correction and the retraction of posterior teeth.

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References

1. Burstone, Charles J.: Vistas in Orthodontics, Lea and Febiger, 197-213, 1962.
2. Atta, Alaa Eldin: Force Magnitude and Center of Rotation; A Histologic Study in Rhesus Monkey. 1964. Masters thesis, Indiana University School of Dentistry.
3. Groves, Murray H.: Threshold Force Values for Anterior Retraction. 1959. Masters thesis, Indiana University School of Dentistry.
4. Kuhn, Robert J.: Force Values and Rate of Distal Movement of the Mandibular First Permanent Molar. 1959. Masters thesis, Indiana University School of Dentistry.
5. Willian, David E.: The Effect of Continuous Torquing Forces on Maxillary Central Incisors in Macaque Rhesus Monkeys. 1963. Masters thesis, Indiana University School of Dentistry.
6. Burstone, Charles J.: The Application of Continuous Forces to Orthodontics, *Angle Ortho.,* January, 1961.
7. Burstone, Charles J.: Rationale of the Segmented Arch, *American Journal of Ortho.,* November, 1962.
8. Sloan, Donald G.: Force Values for Maxillary Anterior Depression. 1961. Masters thesis, Indiana University School of Dentistry.