Force distribution comparisons of various retraction archwires

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There is a dearth of information in the literature regarding the effects of the mechanics that cause incisor retraction during the treatment of extraction cases. Begg[1] put forth a concept called "differential forces in orthodontic treatment." He stated that light forces would move only anterior teeth and heavy forces would move only posterior teeth. Andreasen and Zwanziger[2] evaluated the differential force concept as advocated by Begg. During retraction mechanics, they found that, in general, reciprocal forces cause reciprocal tooth movement with varying and relative rates of space closure. In other words, light forces do not only move anterior teeth, and heavy forces do not only move posterior teeth.

Davis[3] described the retraction of incisors by means of a labial arch wire activated by intraoral elastics and sliding through tubes on the molar clasps of a removable appliance. As needed, he also attached "J-hooks" of an extra-oral headgear for additional retraction force on the incisors. He recommended 100-150 grams of force on each side of the arch wire.

Burstone[4] used specialized prefabricated springs for space closure as an integral part of the segmented arch technique. A "T-loop" spring made from 0.018 inch diameter wire was welded directly to a 0.017 by 0.025 inch base arch wire. According to this technique, the loop is placed anteriorly if posterior teeth are to be maintained, and posteriorly if anterior teeth are to be maintained.

Murphy et al.[5] used an experimental apparatus consisting of a metal framework, a strain gauge, and a Wheatstone bridge. He measured the retraction force delivered to the incisors by a contraction utility arch wire. The lateral incisors were affected by a greater amount of retraction force than were the central incisors using this technique.

Because of the lack of information regarding the effects of anterior retraction forces, the clinician cannot truly evaluate the results of his

Abstract
A photoelastic study comparing the effects of the activations of three retraction arch wires used in orthodontic therapy. Schematic representations of space consolidations, intrusion and root torque are illustrated.

Key Words
Maxillary retraction • Space closure • Crown tip • Root torque • Photoelastic analysis.

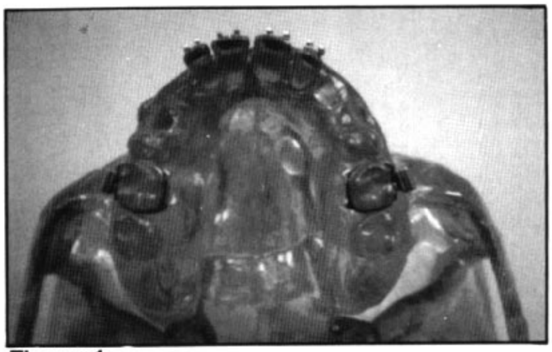

Figure 1

Occlusal view of the maxillary arch of a photoelastic model, simulating a first premolar extraction case. Canines are situated in their orthodontically retracted positions, first molars are banded, and brackets with 0.018" x 0.025" slots are directly bonded to the incisor teeth.

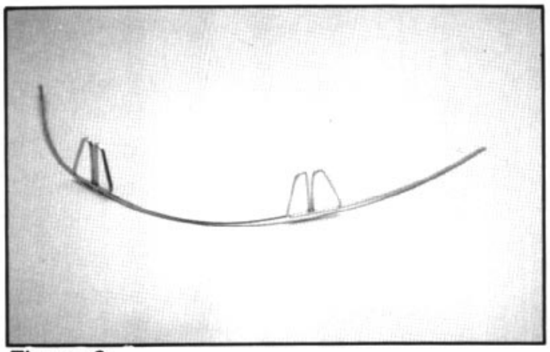

Figure 2

The double delta retraction arch wire. Activating the vertical loops will cause a retraction force on the incisor teeth. Adjusting the horizontal legs gingivally can cause intrusion, and a torquing activation can create some degree of bodily tooth movement.

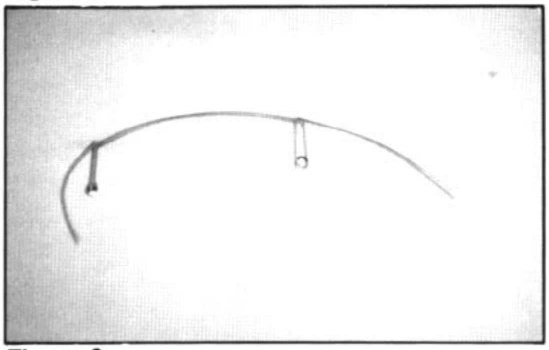

Figure 3

The torquing retraction arch wire is placed so that the loops are directed occlusally.

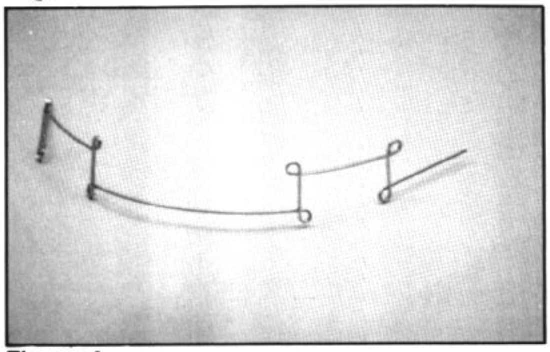

Figure 4

The contraction torquing utility arch wire causes intrusion of the incisors when a "tip back" bend is placed in the molar section of the wire.

closing mechanics. Empirical techniques are often used to achieve intrusion, root torque, and bodily movement of teeth. Therefore, the purpose of this study was to evaluate commonly used retraction arch wires and to visualize the effects of the various activations that are used during orthodontic treatment.

Materials and methods

Photoelastic stress analysis is based upon the property of some transparent materials to exhibit colorful patterns when viewed with polarized light. These patterns occur as the result of alteration of the polarized light by the internal stresses into two waves that travel at different velocities. The patterns that develop are consequently related to the distribution of the stresses within the material.

The quasi-three-dimensional technique was used in this investigation.[6] This approach embodies some of the advantages of both the two-and three-dimensional techniques and uses models with accurate geometric fidelity. The main difference between the quasi-three-dimensional techniques and the true three-dimensional technique lies in the means by which the stresses are observed and recorded. With the two- and three-dimensional techniques, models, or sections of models, are examined that do not have any significant stress variation through the model or section thickness. The quasi-three-dimensional technique does not impose the restriction of planar stress distribution. In fact, this restriction is accepted as a limitation of the technique. However, in addition to the advantage of good geometric fidelity is the advantage of being able to apply multiple, complex force systems with various appliances placed on the model. Unlike the two-dimensional technique, there is no restriction to in-plane forces and stresses. Further, unlike the three-dimensional technique, the model need not be destroyed to obtain the photoelastic data. The main disadvantage of the quasi-three-dimensional technique is the inability to obtain the true three-dimensional stress distribution within the model.

A three-dimensional anatomic model of a human skull was fabricated for photoelastic analysis. Individual simulants were employed to represent the teeth* and bone.** Various anatomic structures (such as the bones of the calvarium and cranial base) were molded as complete integral units. Bones of the midface (such as maxilla, zygomatic arch, vomer and palatine) were molded separately. All the different parts of the model were assembled in their appropriate positions by covering the anatomic sutural areas with an adhesive and maintaining this relation until setting was complete.

The material used to model the bones is different from that used in previous studies.[7,8] In this investigation a low modulus material was used to facilitate optical activation by the low forces generated by the appliances under consideration.

The teeth were placed in the photoelastic model to simulate a first premolar extraction

**PL-1, Photolastic Inc., Raleigh, NC*

***Solithane 113, Thiokol Chemical Corp., Trenton, NJ*

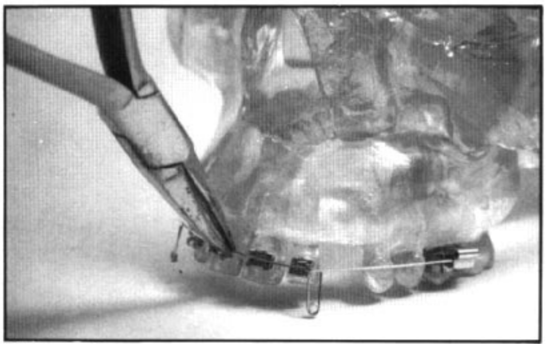

Figure 5

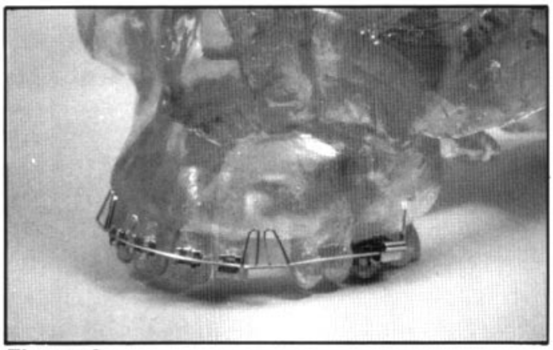

Figure 6

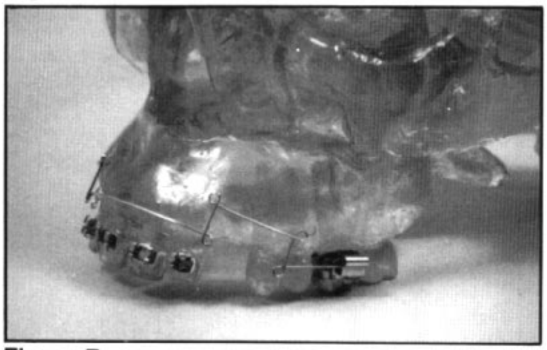

Figure 7

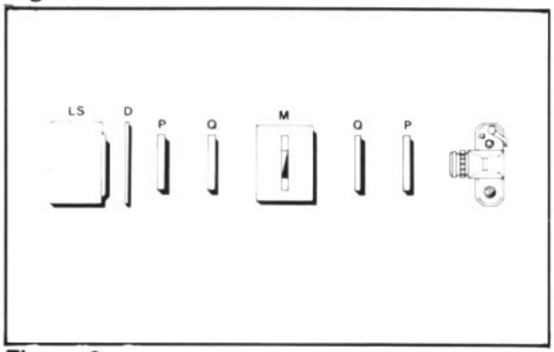

Figure 8

Figure 5

Torquing activation was placed in the anterior sections of all retraction arch wires tested. The activation shown on the torquing retraction arch wire would cause lingual root tipping of the incisor teeth.

Figure 6

By activating the arch wire and "cinching back" on the molar tubes a retraction force was placed on the incisors. Illustrated here is the retraction activation of the double delta arch wire.

Figure 7

By placing "tip back" bends in the molar sections of the contraction torquing utility arch wire, an intrusive force was placed on the incisors. Note the position of the anterior segment of the arch wire prior to attaching it to the incisor brackets.

Figure 8

After activation of the arch wires, the photoelastic model was examined in the field of a circular polariscope. M: model; Q: quarter wave plates; P: polarizer; D: diffuser; LS: light source.

case. The canines were situated in their orthodontically retracted positions after removal of the first premolars. First molars were banded and 0.018″ X 0.025″ brackets were directly bonded to the maxillary incisor teeth (Figure 1).

Various retraction arch wires were constructed using 0.016″ X 0.016″ Blue Elgiloy* wire. Although there is .002″ difference between the inciso-gingival dimensions of the bracket and the wire, effective lingual root torque of the teeth can be accomplished if sufficient torque is placed in the wire. A commonly used retraction arch wire, the "double delta," was the first retraction mechanism tested (Figure 2). Its name reflects the design of the closing loops, and clinical observations indicate mesiodistal activation of this arch wire will retract the incisors with concomitant lingual crown tipping. Adjustment of the horizontal legs gingivally, can cause the incisors to intrude, and a torquing activation can lead to bodily movement.

Figure 3 shows the torquing retraction arch wire. Activation of this appliance supposedly causes a greater amount of lingual root torque of the incisors than other types of contraction arch wires.[9] Also used in this study was the contraction torquing utility arch wire (Figure 4). Activation of this mechanism causes most of the desired tooth movements during incisor retraction, such as space consolidation, intrusion and lingual root torque. All of the arch wires tested were subjected to approximately 45° lingual root torque (Figure 5) and contraction activations (Figure 6). A tip back bend was placed in the contraction torquing utility arch wire which produced an intrusive force on the incisor teeth (Figure 7). With the arch wires in place and appropriately activated, the photoelastic model was examined in the field of a circular polariscope (Figure 8). All pertinent areas of the skull were examined at several different angles to the incident polarized light vector to obtain a more complete picture of the location of the isochromatic fringes. In conjunction with the photoelastic observations, the directions of motion of the teeth were also monitored with a dial gauge accurate to 0.0001."*

Table I reveals the activations that were made on the three different arch wires in this investigation. The activations are indicative of those that are commonly used in clinical practice. For example, the double delta and torquing retraction arch wires are usually used in the correction of open bite malocclusions where intrusion and torque of incisors are not indicated. On the other hand, the contraction torquing utility arch wire is used when there is an anterior deep bite, hence the need for intrusion and lingual root torque in conjunction with the retraction activation.

Results

Prior to placement and activation of the arch wires, the photoelastic model was essentially stress free. Figure 9 is a schematic representation of the photoelastic stresses observed in the model due to activation of the double delta arch

**Rocky Mountain Orthodontics, Denver, CO*

**Mitutoyo Mfg. Co., Ltd., Japan*

Figure 9

Schematic representation of the stresses observed photoelastically due to the retraction activation of the arch wires. Interdental stresses are associated with distal crown tipping of the incisors. Apical stresses are indicative of labial root or lingual crown tipping.

Figure 10

Stresses produced at the edentulous space due to the activation of the "upside down" closing loop are representative of incisor distal retraction. Less stress at the apices of the incisors than the previous figure is indicative of less lingual crown tipping.

Figure 11

Stresses produced by a lingual root torquing activation on the torquing retraction arch wire. Note that there is no activity at the edentulous space. Stresses at the apices are indicative of lingual root torque and intrusion.

Table I

Arch Wire	**Activation Employed**
Double Delta	R
Torquing Retraction	R, T, T+R
Contraction-Torquing Utility	R, R+I,R+I+T

R = retraction T = torque
I = intrusion

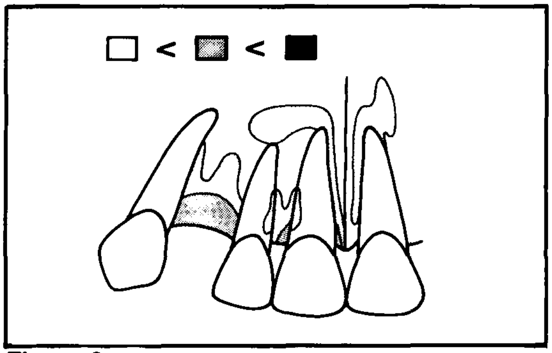

Figure 9

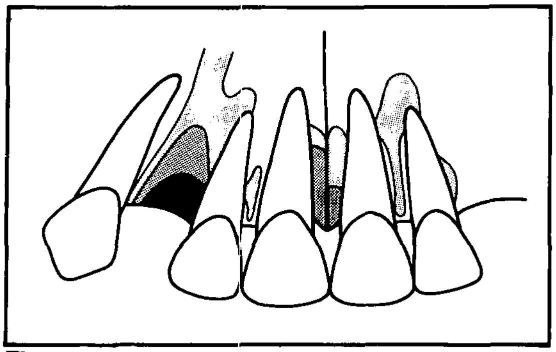

Figure 10

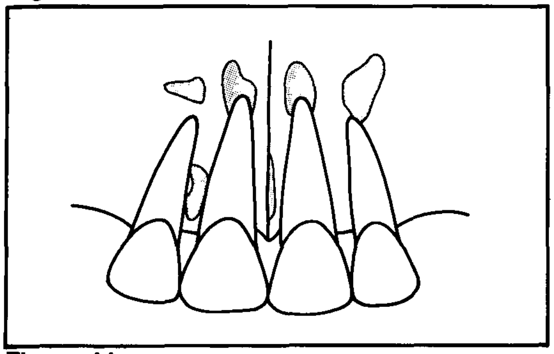

Figure 11

wire. This pattern is representative of the stresses produced by all of the arch wires during retraction activations. The stress activity seen between the central incisors, central and lateral incisors, as well as between the lateral incisor and canine in this figure is indicative of distal crown tipping of the incisors. The stresses seen at the apices of the incisor teeth, as well as the motion observed, reflect lingual crown or labial root tipping.

Figure 10 reveals the stresses produced by the activation of the torquing retraction arch wire. It can be seen that high stresses are concentrated at the edentulous space indicative of incisor distal retraction. The activation of the "upside down" closing loops produced lower stresses at the apices of the incisors than the double delta arch wire. This would be indicative of a less severe lingual crown tipping of these teeth than that produced by the activation of the double delta arch wire.

Figure 11 reveals the stresses produced by the torquing retraction arch wire with no activation other than torque. As can be seen, there is virtually no activity at the edentulous space, but there are stresses that have developed at the apices of the incisors as the result of combined intrusion and lingual root torque.

Figure 12 shows the results of the torquing and retraction activations on the torquing retraction arch wire. The stresses concentrated at the edentulous space have lessened dramatically from that seen in Figure 10 with this arch wire but without the torquing activation. It is apparent that the lingual root torquing activation produces an opposing effect on the incisors compared to the retraction activation. The activation of this arch wire negated the lingual crown tipping seen previously, and the stress observed on the apex of the right lateral incisor is indicative of intrusion.

These retraction arch wires have similar effects on the posterior or anchor teeth of the dentition. As illustrated in Figure 13, the photoelastic activity on the mesial of the molar would produce mesial crown tipping of this tooth when the retraction arch wires are activated.

Figure 14 shows the results of retraction and tip back activations of the contraction torquing utility arch wires. The photoelastic activity at the apices of the incisors and at the edentulous area is indicative of a combination of incisor intrusion as well as labial and distal crown tipping. Again, the activation of this wire negated the lingual crown tipping as seen before.

Figure 15 reveals the same arch wire with the addition of the torquing activation. Notice the continuous photoelastic activity along the entire length of the root of the right lateral incisor. This means that the forces produced by the torquing utility arch wire cause a relatively effective bodily movement action.

Discussion

The stress differences resulting from the activations of the double delta arch wire and the contraction torquing wire are illustrated in Figures 9 and 10. Note that the stresses at the apices are greater with the double delta arch

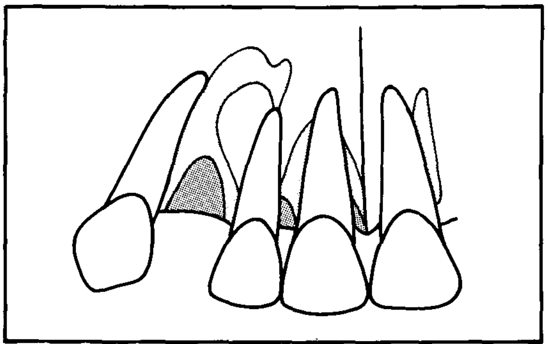
Figure 12

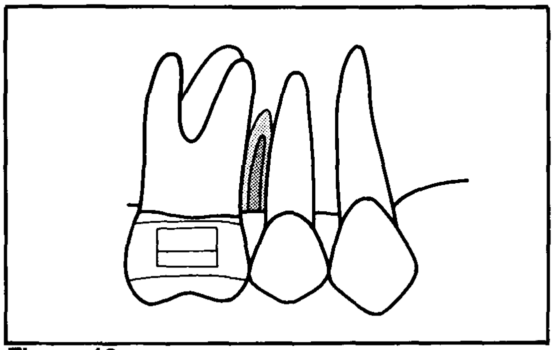
Figure 13

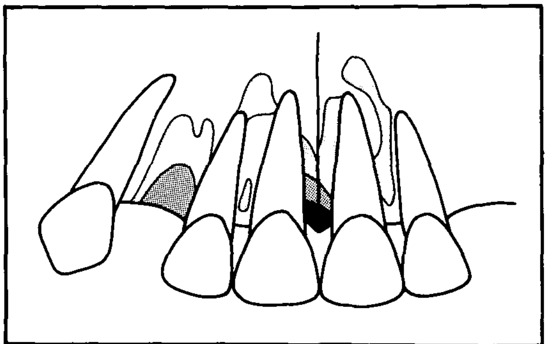
Figure 14

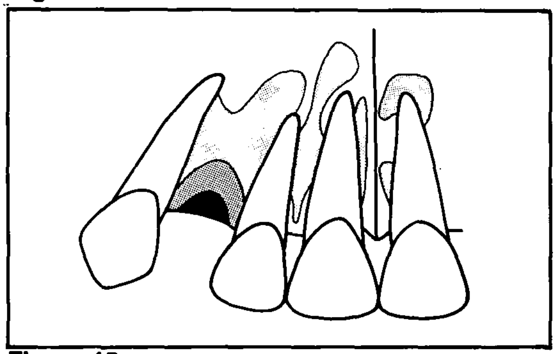
Figure 15

Figure 12
Stresses produced by the torquing and retraction activations on the torquing retraction arch wire. Stresses at the edentulous space are less than with only the retraction activation of the same arch wire (Fig. 10).

Figure 13
Photoelastic activity on the molar teeth was the same during the retraction activation of all the arch wires. Stresses along the mesial of the molar would produce a mesial tipping of the tooth.

Figure 14
Stresses produced by the retraction and tip back activation of the contraction torquing utility arch wire. The activity seen at the edentulous area and at the apices of the incisors is indicative of distal and lingual crown tipping.

Figure 15
The contraction torquing utility arch wire with the addition of a lingual root torquing activation. The continuous photoelastic activity along the entire length of the right lateral incisor root is indicative of bodily movement of the teeth.

wire, but that the stresses caused by the retraction forces in the edentulous area are greater with the contraction torquing wire. This means that even without torque in the wire, the latter causes less lingual crown tipping when activated than does the double delta arch wire.

The clinical observation during the activation of a retraction arch with the closing loop pointing toward the apices of the anterior teeth is for the crowns of the incisors to tip lingually. On the other hand, when the closing loop is directed toward the incisal, the activation of this type of retraction mechanism causes a labial crown tipping. These two examples are illustrated in Figures 16 and 17 respectively. Figure 16a shows the moments developed during activation of the conventional retraction mechanism. Because of the curvature of the wire, the moment shown will produce the lingual crown tipping and labial root movement. Activation of the torquing retraction arch wire is shown in Figure 17a with the associated moments. Again, the curvature of the wire results in the moment causing a labial crown tipping and a lingual root movement.

With only a torque activation of the contraction torquing arch wire, the net effect is a lingual root torquing movement as illustrated at the apices of the incisor teeth in Figure 11. Figures 14 and 15 illustrate activations of the contraction torquing utility arch wire. Both reveal the stresses caused by tip back and retraction activations, with the addition of torque in Figure 15. The addition of torque to this retraction arch wire produces forces that are more uniform along the entire length of the incisor roots. This stress pattern indicates that the resultant tooth movement would be more bodily than without the torquing activation.

It is apparent from this investigation that the retraction arch wires used in this study will not perform all the desired tooth movements. The double delta arch wire will retract the incisors, but its activation will also produce lingual crown tipping which will tend to deepen the bite. The contraction torquing arch wire will retract the incisors effectively, but because of the position of the closing loops it will reduce the lingual crown tipping even without placing torque in the arch wire. The contraction torquing utility arch wire will also retract the incisors. However, lingual root torque must be placed in the wire to prevent lingual crown tipping. This contraction wire, especially with the addition of the tip back bend will cause a very effective intrusive movement of the incisor teeth.

While the activations considered in this study were based on those commonly used in clinical practice today, some additional combinations of activations may produce helpful results. For example, the inclusion of intrusion together with torquing and retraction for the torquing retraction arch wire might provide some clinically useful effects. These activations, as well as other combinations for all three arch wires tested, would form the basis for an effective follow-up investigation.

Figure 16

A) Activation of conventional closing loop mechanics produce moments on the arch wire as seen in this illustration.

B) The moment applied to the tooth is represented by the solid arrow. The resulting tooth motion is represented by the open arrows.

Figure 17

A) Activation of the torquing retraction arch wire produces moments within the arch as seen in this illustration.

B) The resulting tooth movement is labial crown tipping of the incisors. The moment applied to the tooth is represented by the solid arrow. The resulting tooth motion is represented by the open arrows.

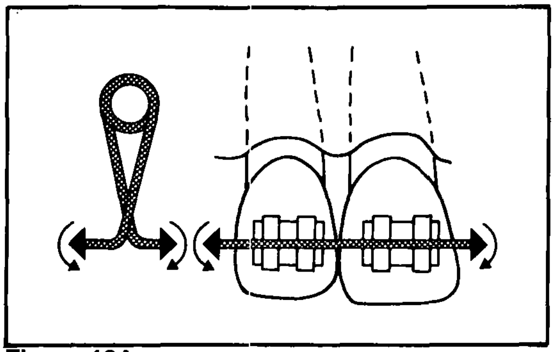

Figure 16A

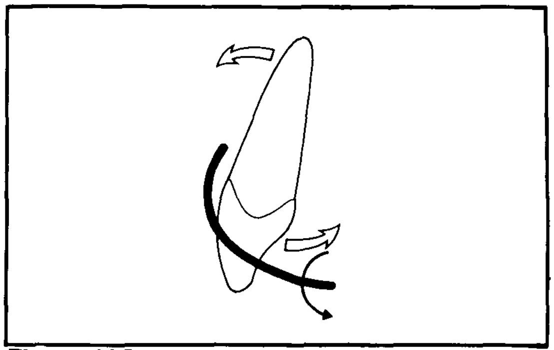

Figure 16B

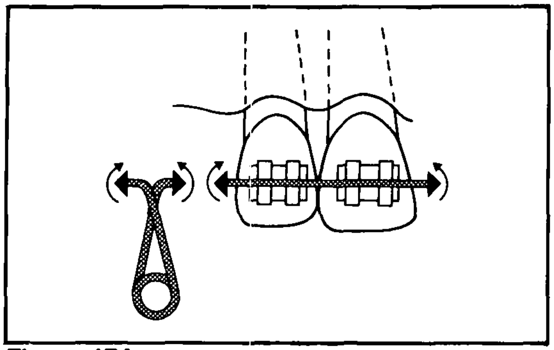

Figure 17A

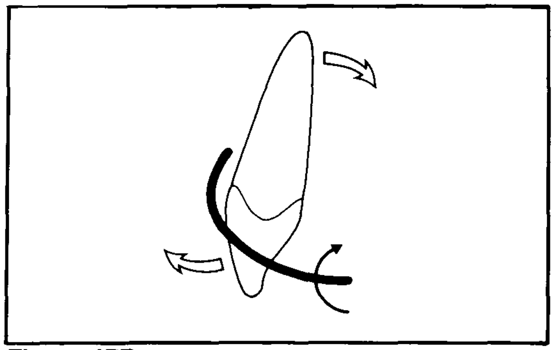

Figure 17B

Summary and conclusions

Three contraction arch wires were studied in this investigation: double delta, contraction torquing arch, and contraction torquing utility arch wire. The activations studied were intrusion, retraction and torque.

In clinical terminology the results of the research conducted on these various retraction arch wires dictates to the clinician which one should be used based on the objectives of the treatment plan. In other words, if deepening of the bite is indicated, the clinician should use the double delta arch wire which would produce a lingual crown tipping and possibly extrusion of the incisors during retraction. However, if a deep overbite exists prior to anterior tooth consolidation, the contraction torquing or contraction torquing utility arch wires should be used since they were shown to produce the most effective lingual root torquing during incisor retraction. This action would not result in deepening of the bite.

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