REVIEW ARTICLE   Open Access

Biomechanics in Orthodontics Anchorage Considerations-A Review

Khalid Ashraf1, Rohit Kulshrestha[2]*, Rachel Thomas[3], Sandeep Singh[4], Harmeet Kaur[5], Khusali Rathod[6]

Oral Medicine and Diagnostic Science Department, College of Dentistry, King Saud University, Riyadh, Saudi Arabia.

[1]Orthodontist, SPES Hospital, Tohana, Haryana, India

[2]Senior Lecturer, Department of Orthodontics and Dentofacial Orthopedics, Terna Dental College and Hospital, Navi Mumbai, Maharashtra, India

[3]Reader, Department of Orthodontics and Dentofacial Orthopedics, Terna Dental College and Hospital, Navi Mumbai, Maharashtra, India

[4]Senior Lecturer, Department of Orthodontics and Dentofacial Orthopedics, Terna Dental College and Hospital, Navi Mumbai, Maharashtra, India

[5]Post Graduate Student, Department of Orthodontics and Dentofacial Orthopedics, BBD Dental College, Lucknow, Uttar Pradesh, India

[6]Post Graduate Student, Department of Orthodontics and Dentofacial Orthopedics, Terna Dental College and Hospital, Navi Mumbai, Maharashtra, India

*Corresponding Author: Rohit Kulshrestha, Terna Dental College Nerul Navi, India, Tel. No: +919870499761; Email: kulrohit@gmail.com

Abstract

To anchor is to secure firmly, to hold an object against movement; anchorage is that which provides the secure hold. Specifically, orthodontic anchorage is the ability to prevent tooth movement of one group of teeth while moving another tooth or teeth. The nature of tooth movement depends on the ratio of the applied moment relative to the applied force (M/F ratio) at the orthodontic bracket. The way a tooth moves is dependent on the force and moments applied on the bracket (via elastic, coil, loop, etc.), and the actual force distribution about the periodontium (stress-strain relationship). The force distribution is a function of the tooth's center of rotation. The aim of this article was to review the different mechanics seen and used during anchorage preparation.

Anchorage from a Biomechanical

The basic techniques for anchorage control generally rely on 3 essential similarities: (1) extra oral forces on the anchorage unit (headgear), (2) intermaxillary elastics (3) tipping movements of the active teeth while simultaneously discouraging tipping of the anchorage teeth. Patient compliance is required for headgear and elastic wear without which, the control of tooth movement is lost, and treatment outcome may be compromised. Anchorage is maintained by promoting different types of tooth movement for the active teeth versus the anchor units [1].

The Effect of a High M/F Ratio Applied to the Anchor

An applied force at the crown produces uncontrolled tipping as a result of the moment of the force. The applied moment (moment of the couple) counteracts the tipping effect of the force. The applied moment acts in the opposite direction of the moment of the force. It moves the root(s) toward the extraction space. In addition, as the magnitude of the applied couple increases, the rotation of the tooth would move the crown away from the space (Figure 1) [2].
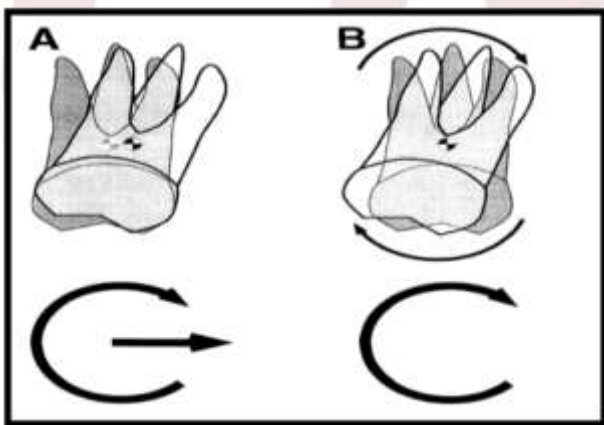

Figure 1: The effect of a large M/F ratio on tooth movement. A large M/F ratio produces root movement (A). A pure moment would produce only rotation, which would result in distal crown movement (B).

Conversely, a low M/F ration produces tipping. With the apex remaining stationary, the crown tips toward the extraction space. Geometrically, the result is greater tooth movement at the occlusal plane relative to a tooth undergoing translation. Figure 2 shows a comparison of tipping versus translation, the center of resistance of the tooth for each example is displaced equally. The crown movement, however, is noticeably greater for the tipped tooth. This shows how tipping movements can result in greater movements of teeth from a clinical perspective.
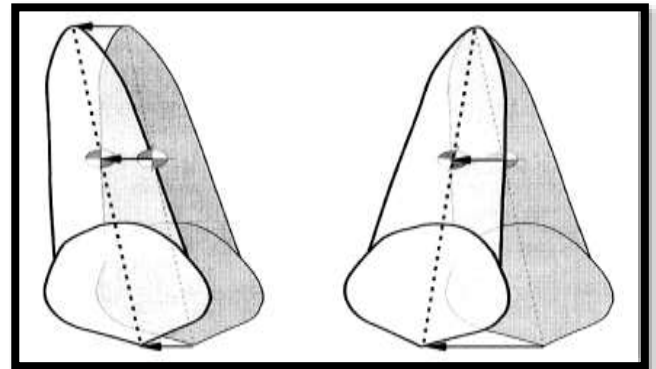

Figure 2: Tipping produces more movement at the crown or occlusal plane compared with translation. For both teeth in this illustration, the center of resistance of the tooth is displaced the same distance.
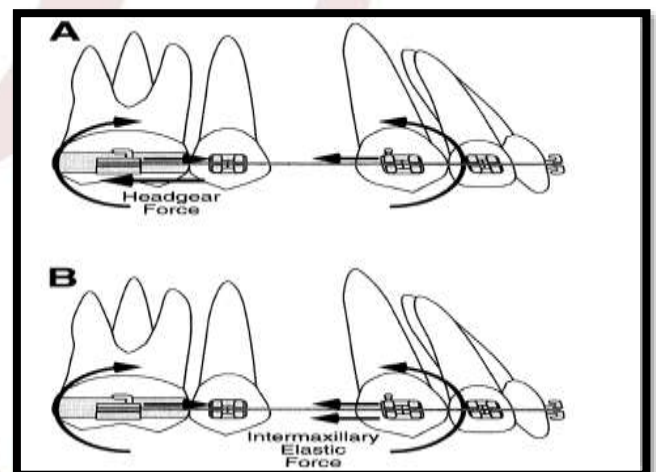

Figure 3: The effect of changing the force magnitude on the M/F Ratio. Headgear is a means of decreasing the mesial force to the posterior teeth (A). Intermaxillary elastics (Class II elastics) increase the distal force to the anterior teeth (B).

In its simplest form, headgear acts to produce a distal force on the anchorage teeth. By acting in opposition to the reaction force from a spring or chain elastic, the headgear reduces the net force on the posterior teeth (M/F posterior>M/F anterior) (Figure 3A). Although there may be additional headgear effects, the aim conceptually is to retard the mesial forces ion the posterior teeth (For example, increase the retraction force on the anterior teeth (M/F posterior>M/F anterior) (Figure 3B). Another means of increasing the retraction force is by the use of J-hook headgear applied to the anterior teeth. The applied moment is determined by the wire-bracket relationship [3].

The application of unequal moments must also satisfy Newton's laws. Because the moments on each end of the spring are unequal, the total force system must have additional effects. Vertical forces, intrusive to the anterior and extrusive to the posterior, are also acting. (The vertical force magnitude depends on the difference in the 2 moments and the distance between anterior and posterior attachment points) (Figure 4). It also results in occlusal plane discrepancies between the anterior and posterior teeth. The posterior teeth may be positioned with the crowns distally tipped and the roots mesially oriented [3].
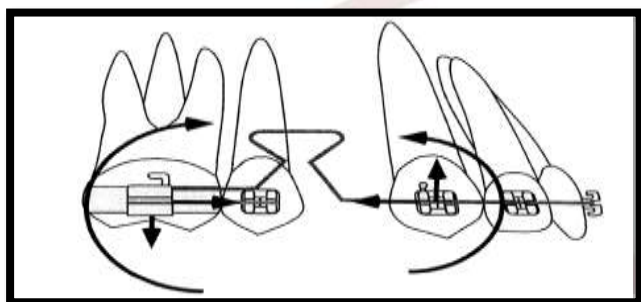

Figure 4: The force system from differential moment orthodontic appliance designs for space closure.

The canines commonly have a root-mesial axial inclination and the incisors are excessively upright. This situation is a natural consequence of the force system used but may also be an advantage given appropriate malocclusions (anterior protrusion with excessive dentoalveolar height and gingival display). An appropriate stage of root correction after space closure prepares the occlusion for orthodontic finishing details. Other factors being equal, an increase in wire stiffness has the effect of establishing greater moments at the engaged teeth. Increases in stiffness may be accomplished by using composite springs with incorporation of wires showing different modulus of elasticity, with suffer section engaging the anchorage units [4].

<div style="background:#8B1A3A;color:white;text-align:center;padding:8px">

Clinical Techniques Using Differential Moments for Anchorage Control

</div>

The data were collected, summarized, and coded. All the statistical analyses were performed using the Statistical Package for Social Sciences (BM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp). The following statistical procedures were performed: the construction of frequency distribution tables, one-way analysis of variance (ANOVA), and post-hoc tests. $P \leq 0.05$ was considered statistically significant.

The T-loop spring described by Burstone and subsequently refined or modified as a simple yet effective device for

controlled space closure. The core principle of loop design for all these springs is increased stiffness of the wire on the anchorage side of the spring [5]. All conversely, asymmetric positioning of the loop towards the anchorage teeth has a similar effect because wire stiffness is inversely related to the third power of the length, an off-centered or asymmetrically positioned spring will deliver greater moments to the teeth that it approximates (Figure 5) [6].
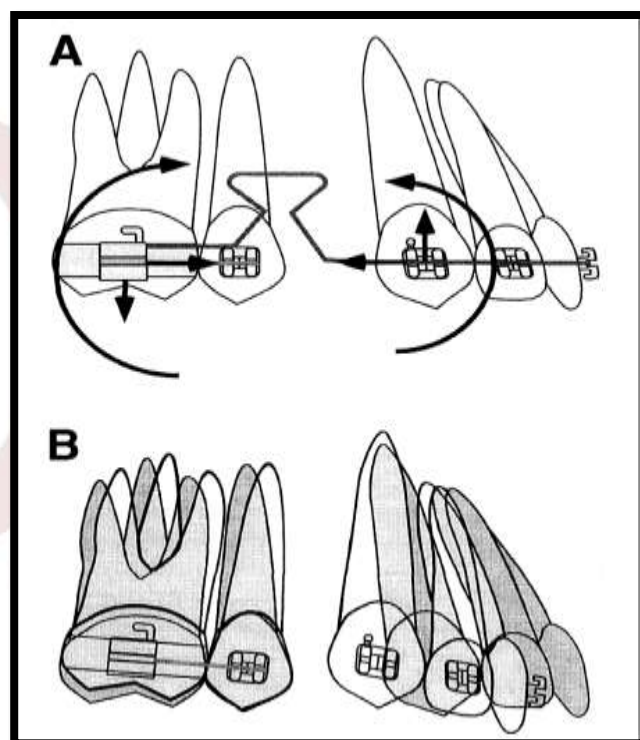

Figure 5: Anchorage control with a differential moment strategy through the use of a T-loop spring. A T-loop positioned toward the posterior attachment increases the moment to the posterior teeth and decreases the moment to the anterior teeth (A). The expected tooth movements, the anterior teeth are expected to tip distally while the posterior teeth show root correction (B).

Another method of anterior retraction that uses a differential moment strategy for anchorage control is combined incisor intrusion and retraction. This simple yet effective appliance uses the tip back moment of the intrusion arch for creating the large posterior M/F ratio. The retraction force is applied with either coil springs or elastic chain (Figure 6). By carefully controlling the intrusive and retraction forces, the overbite and over jet can be simultaneously corrected. Careful monitoring is crucial for successful anchorage control during space closure. A frequently overlooked consideration in anchorage control the first-order side effects of space closure. The mesially directed, buccally located force on the molar will tend to produce a mesially inward rotation. This rotation gives the appearance of anchorage loss when viewed from the buccal

perspective. However, distalization of the molar may not be necessary; a mesially-outward first-order rotation may be all that is needed for regaining the desired molar position. A transpalatal arch provides an excellent means for preventing this side effect or actively correcting it [7].

Figure 6: Combined anterior retraction and deep overbite
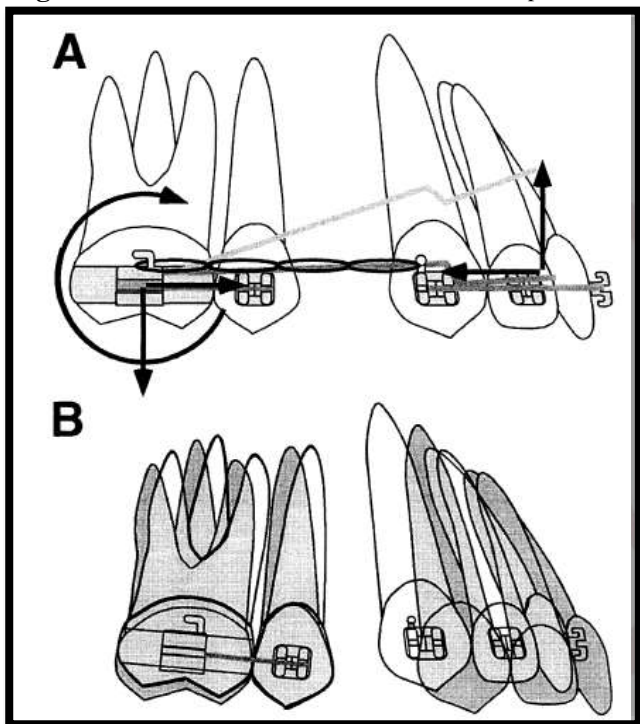
correction with posterior anchorage control. An intrusion arch is used to create the moment on the posterior segment with the concurrent intrusive force on the anterior teeth and extrusive force on the posterior teeth. A chain elastic or coil spring is used to create the retraction force (A). The anticipated tooth movements would be intrusion and retraction of the anterior teeth following the line of action of the resultant force and molar tip back which aids in anchorage preservation (B). Studies have investigated effectiveness of differential moment strategy for anchorage control.

## Biomechanics of Root Correction

Incisor root correction

Incisors that need root correction or lingual root torque after completion of space closure require a counter clockwise moment applied to them with a center of rotation at the brackets. This results in lingual root movement of the anterior teeth. The magnitude of the moment necessary to correct the axial inclinations of the maxillary central incisors is about 1500 g-mm or less per side (3000 g-mm total) 2000-2500 g-mm per side (4,000 to 5,000 g-mm total) is used to correct the axial inclinations of the four maxillary incisors [8]. Vertical forces are developed on the anterior teeth and on the posterior teeth as a

result of the moment applied to achieve anterior root correction. The anterior teeth are extruded while the posterior teeth experience an intrusive force.

Anchorage requirements are critical during root correction of the anterior teeth. Rowboat effect, moving the entire maxillary dental arch forward and resulting in a more Class II dental relationship, may be observed as the roots of the anterior teeth are moved lingually. The use of headgear to support anchorage during anterior root correction may help to minimize or eliminate this side effect. The root spring used for anterior root correction may be fabricated using 0.022×0.016 inch (ribbon wise) titanium molybdenum alloy (TMA), or 0.021×0.025-inch (edgewise) TMA, to be inserted into 0.022×0.028-inch edgewise brackets. The root spring is placed into the brackets of the anterior teeth, stepped up around the canines and premolars, and extended distally as a cantilever with hooks mesial to the first molars (Figure 7) [9].

Figure 7: Frontal view of a root correction spring in
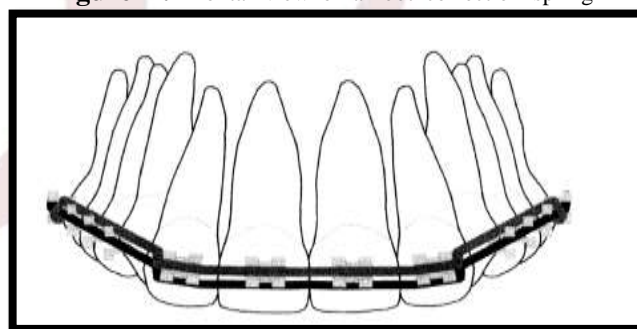
place in the incisors and a bypass archwire stepped around the incisors and inserted into the brackets of the posterior teeth.
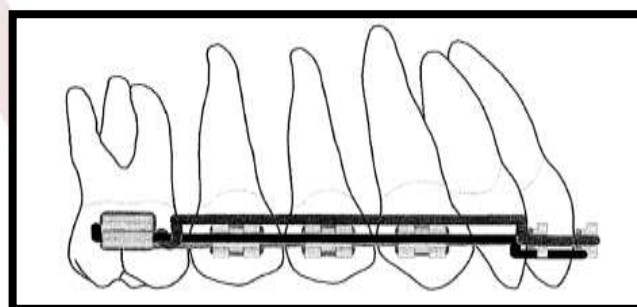

Figure 8: Sagittal view of the root spring hooked on the bypass arch wire mesial to the first maxillary molars.

The distal extension for the root spring will be attached to a continuous bypass arch wire that engages the buccal segments and is steeped around the anterior teeth undergoing root correction. The bypass arch wire is typically made of 0.017×0.025-inch TMA or 0.018 inch stainless steel. It is stepped occlusally around the brackets of the anterior teeth to be corrected (Figure 8).

Pre-activation bends are placed at the gingival position of the anterior step up and a gentle curvature is incorporated bilaterally along the posterior cantilever (Figure 9). The amount of force is measured on the right and left sides and trial activation is made on each side of the spring [10].
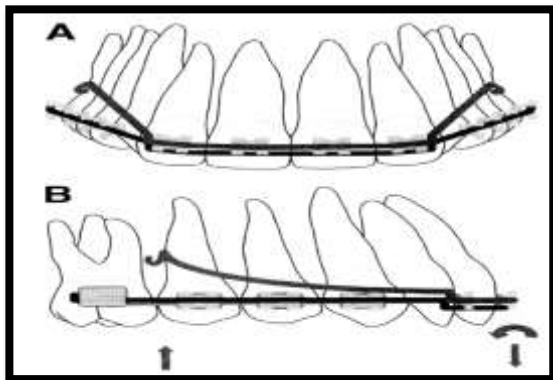

Figure 9: Frontal view of an anterior root correction spring with bilateral activations (A). Once activated, the distal arms of the root spring will be pulled occlusally and hooked on the bypass arch wire (B).

Biomechanics of Headgear in Class II Dental and Skeletal Corrections

Biomechanics

A headgear can deliver only a net single, simple force. To determine the effects of headgear force, one merely needs to examine the line of action of the force with respect to the body to which it is applied-e.g., tooth, arch, or maxilla. Figure 10A shows an occipital pull headgear in place. Figure 10B demonstrates that the strap's pull-the force's line of action is well above the center of resistance of the maxillary first molar. At the maxillary first molars center of resistance, the headgear force system has a distal component, an apically directed vertical component, and a large root-distal movement [11].

Figure 10: A. Occipital-pull headgear. B. Face bow typically used with occipital pull.
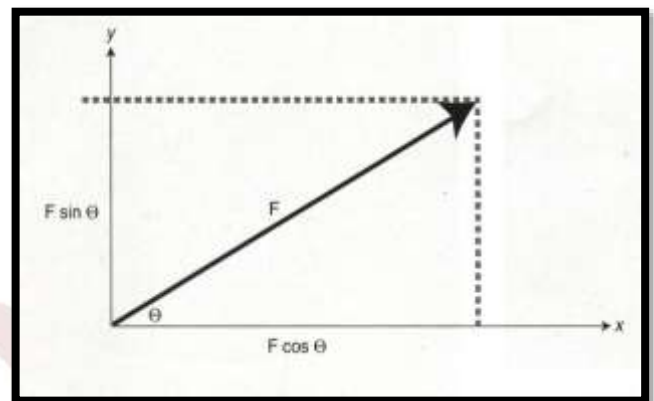

Figure 11: Resolving a force into its components along axes of interest.

In cases where combination head gears are used vector addition is accomplished by resolving the force along its line of action into its components along the horizontal and vertical axis as shown in Figure 11. An example of doing so is shown for Class II elastic force to the maxillary arch in Figure 12.
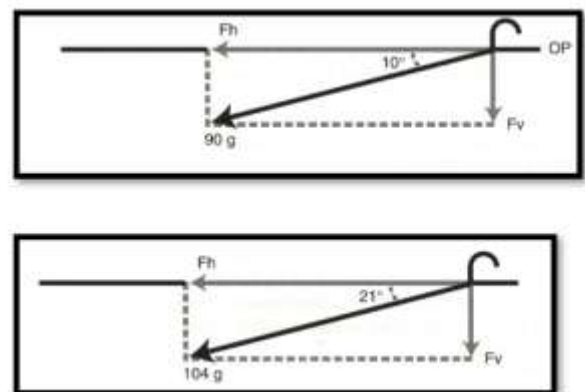

Figure 12: Example of resolving a force into its components.

Figure 13 shows vector addition of two forces. This addition is accomplished by adding the horizontal components of each force and by adding vertical components of each force, then adding them to find the net vertical component of the resultant force. Figure 13 shows parallelogram addition of combination headgear force components.
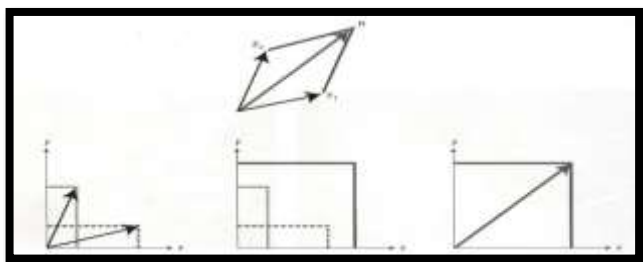
Figure 13: Vector addition.

Force Constancy

It is not known whether a constant force produces a rapid movement or an intermittent force does. However clinical experience indicates that intermittent force can be very efficient indeed [12]. For example, the effectiveness of finger and thumb sucking habits in moving teeth and bones in patients with these aberrant habits. Also clinical experience shows that headgear wear need not be 24 hours a day to be effective. Depending upon the results required, intermittent wear at the level of 12-14 hours per night-sometimes as much as 16 hours per night and at times as little as 10 hours per night-is sufficient to achieve specific treatment goals.

Clinical Applications of Head Gear Force

There are four main uses of headgear force in contemporary treatment of Class II malocclusions [13]:

1. Anchorage control.

2. Tooth movement.

3. Orthodontic changes.

4. Controlling the cant of occlusion plane.

Anchorage Control

In Class II extraction treatment, to ensure that buccal segments of teeth do not move mesially when anteriors are retracted. In a general sense, headgear force is used to control the side effects of intra oral mechanics which results in eruption of teeth. An eruptive force applied to a molar is shown in Figure 14A. Such side effects are seldom desired.
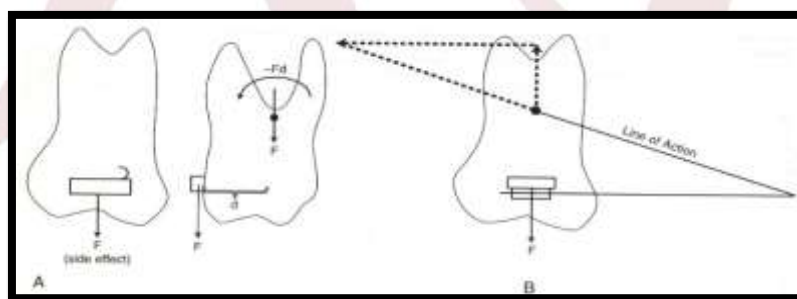

Figure 14. A. Vertical force on molar tube, a side effect from intraoral mechanics.

B. Vertical component of occipital headgear force negates extrusive intraoral force side effect.

The side effect force tends to extrude the molar, and the moment of the force-expressed at the center of resistance of the tooth-produces a root-buccal, crown lingual moment tending to tip the molar crown into lingual cross bite. Applying an occipital headgear force, whose line of action is shown in Figure 14B, produces a vertical intrusive component of force that negates the vertical extrusive force of the side effects even though the head gear force is not applied continuously. This vertical force is of a much higher force level than the force of the side effect. The line of action is determined after the headgear strap has been applied to the outer bow, and the outer bow has deflected to its resting position. One needs to see the angle and level of the final line of action after the strap forces have been applied to know exactly the force of the headgear system.

Tooth Movement

In class II patients, if one adjusts the level of the outer bow such that a horizontal force is produced that passes through the center of resistance of the maxillary first molar, and the patient wears the headgear at the level of 14 hours each night consistently, than the molars will move distally 2 mm in 24 months without tipping [14]. If the line of action of the headgear force is adjusted so that there is a vertical component tending to

intrude the molar, as shown in Figure 14B, the headgear forces tend to prevent extrusion from intraoral side effects. If the line of action of headgear force has an extrusive vertical component, the molar will extrude, independent of the individual patient's skeletal pattern, unless there is a large intrusion force from the arch wire on the molar. This situation is now usual in intraoral mechanics.

Orthopedic Changes

If the headgear force is applied through the center of resistance of maxilla (apical level between the premolars) and a preadolescent patient wears the headgear at least 12 hours each night (at least 14 hours each night for adolescent patients) the forward component of the maxillary growth is redirected [15]. Occasionally, especially in patients who wear the headgear at the level of 16 hours a night, the redirection is in a posterior direction. The total magnitude of growth does not change but its direction is changed.
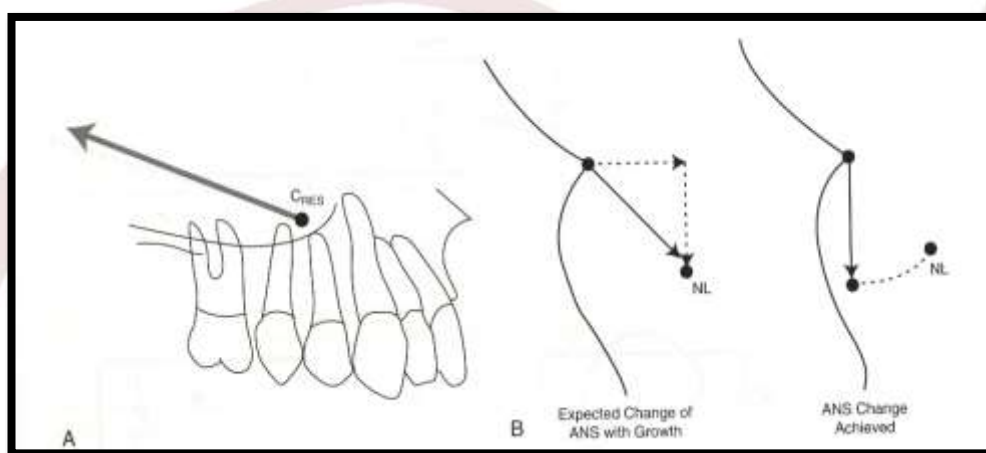

Figure 15. A: Force through the center of resistance of the maxilla. B. Typical redirection of the maxillary growth at ANS as seen on cranial base superimpositions.

Seven sequential steps may be used in logical sequence to design the headgear force system for any orthodontic application. They are:

1. Determine the center of resistance of body to which headgear force is being applied, whether tooth or segment or arch or maxilla.

2. Then determine the force system through the center of resistance that will produce the changes desired. One thinks of the force and moment at the center of resistance (Figure 15).

    (a) Horizontally.

    (b) Vertically.

    (c)   Cant of occlusal plane.

    (d)   How far from the center of resistance, should the force be applied?

As an example (Figure 16), if one wants to steepen an occlusal plane, erupt the unit, the prevent mesial movement of the unit. A unit could be a tooth, segment, arch or maxilla. A cervical headgear with a low outer bow generates a large moment about the center of resistance that will tend to steepen the occlusal plane. The vertical component of the headgear forces acting at the center of resistance will erupt the unit. The distal component will tip the unit distally.

    3. Mentally mark the center of resistance of the patient's cheek.

    4. Choose the type of pull:

    (a) High pull (occipital).

    (b) Cervical.
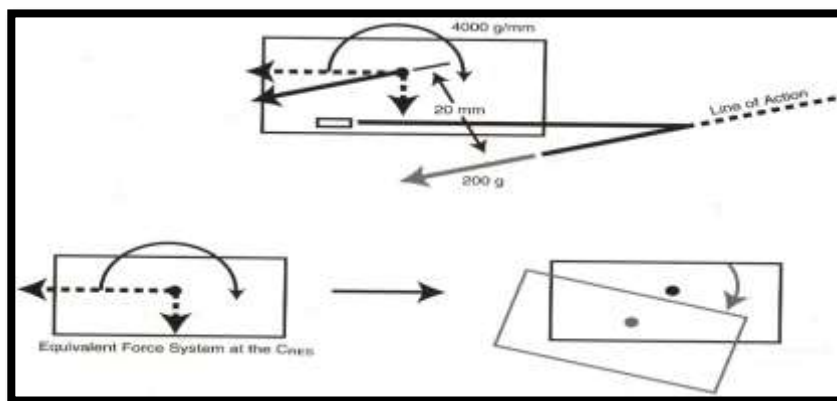
    (c)   A combination of (a) and (b).

Figure 16. Example of a commonly used force system: cervical headgear with low outer bow. Headgear force is shaded. The equivalent force system at the center or resistance is in black.

5. Bend the outer bow angulation and adjust its length to deliver the desired line of action after the strap force is applied.

6. Choose the applied headgear force magnitude:

(a) In rotating the unit-that is, using a large moment in comparison to the applied force through the center of resistance-one should use low strap forces to avoid high local stress in the periodontal ligament (150-200 g per side).

(b) If the line of action of headgear passes close to or through the units center of resistance, 400 to 500 g per side can be used.

7. Monitor for changes as treatment proceeds. Adjust the force line of action and force magnitude as necessary.
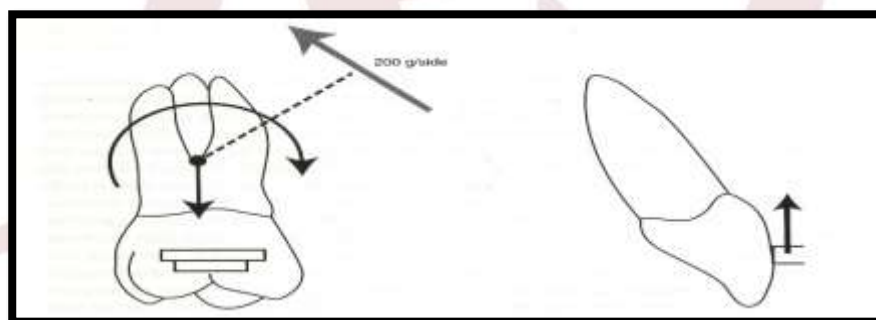

Figure 17: Occipital-pull headgear at the level of 12 hours per night (10 hours per night for conscientious adults) to control side effects from maxillary incisor intrusion via a base arch.

An example of occipital headgear to control the occlusal plane and prevent side effects from maxillary incisor intrusion is given in Figure 17. The headgear force is applied well away from the molars center of resistance to generate a large counter clockwise moment, negating the clockwise moment for the intrusion arch. The outer bow is bent high and is cut short to provide the desired line of action. If using a 0.016 inch stainless steel intrusion arch, 60 g will be generated at the midline if the wire is activated 90° just mesial to the first molar tubes when a single helix is placed in that position. if the patient has a maximum anchorage class II malocclusion, the angulation of the outer bow can be lowered and the headgear force increased to 400-500 g per side. The result will be a larger horizontal distal component of force [16].
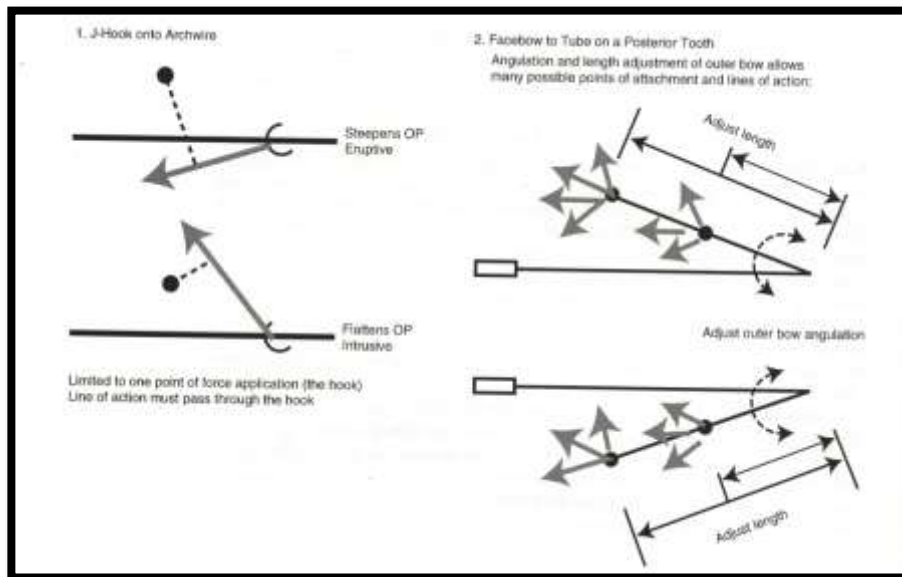
Figure 18: Possible headgear designs.

There are two main possible designs for applying headgear forces, as in Figure 18 one can hook a J-hook headgear to the arch wire. This approach is limited in that one is restricted to one point of force application (wherever one can hook the J-hook). In addition, the line of action may pass through the hook itself. A far more flexible approach is to place the headgear in a tube on a posterior tooth. Having an inner bow and an outer bow allows adjustments of the length and angulation of the outer bow to provide many possible points of attachment and lines of action. There can be many directions of force, and thereof many different M/F ratios applied. This design is more comfortable for patients to wear, and arch wires are not prone to fractures.

Example of Maxillary Headgear

Cervical pull

Figure 19 shows three possibilities for applying cervical pull to a maxillary unit. The example at the top of the figure has the outer bow low. The equivalent force system at the unit's center of resistance has an extrusive component, a distal component, and a large moment that trends to steepen the occlusal plane [17].

Figure 19. Cervical pull headgear examples.

Occipital pull

Figure 20 shows occipital pull headgear. The figure shows occipital pull with the short outer bow angulated high to create the headgear force line of action that is far anterior to the unit's center of resistance. This results in a force system at the unit's center of resistance with a moment that tends to flatten the occlusal plane and distal and intrusive force components. The equivalent force system at the unit's center of resistance has a moment that tends to steepen the occlusal plane and a force with intrusive and distal components. Such a system might be necessary for Class II open bite patients [18].
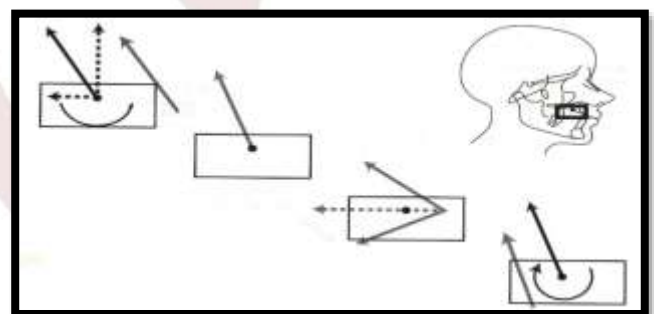

Figure 20: Examples of headgear incorporating occipital pull.

It is often necessary to correct mesial-in rotation of first molars during Class II correction. This can be accomplished by an active transpalatal arch (TPA) or by adjusting the angle of insertion of the inner bow ends into the headgear tubes to effect rotational change, mesial out and distal in, the transverse plane of space while effecting desired changes in the sagittal plane.
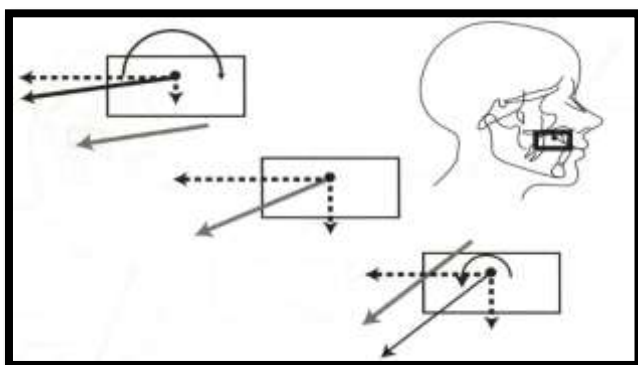
Asymmetric Headgear

Right versus left asymmetries in the molar relationships can be corrected by using transpalatal or lingual arches to correct asymmetric molar axial inclinations and molar rotations. However, if the buccal occlusion is asymmetric, e.g., class I on one side and Class II on the other side, without asymmetries either in molar axial inclinations or in rotations, then correction is performed with asymmetric headgear. Distal forces exist on both sides, but they are three times greater on the long outer bow side than on the short outer bow side (Figure 21). Lateral forces, directed towards the short outer bow side, exist with this headgear. One must therefore watch for cross bite development.

It is usually best to stop using this mechanism if cross bite development begins to occur [19].
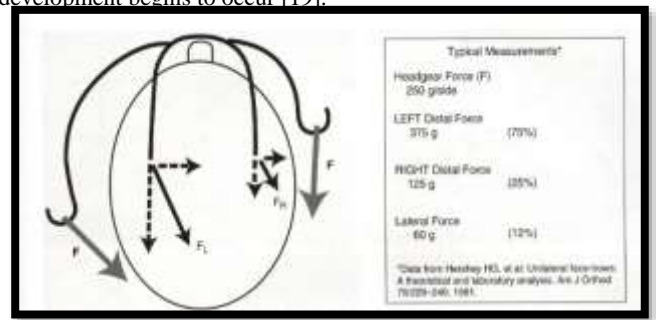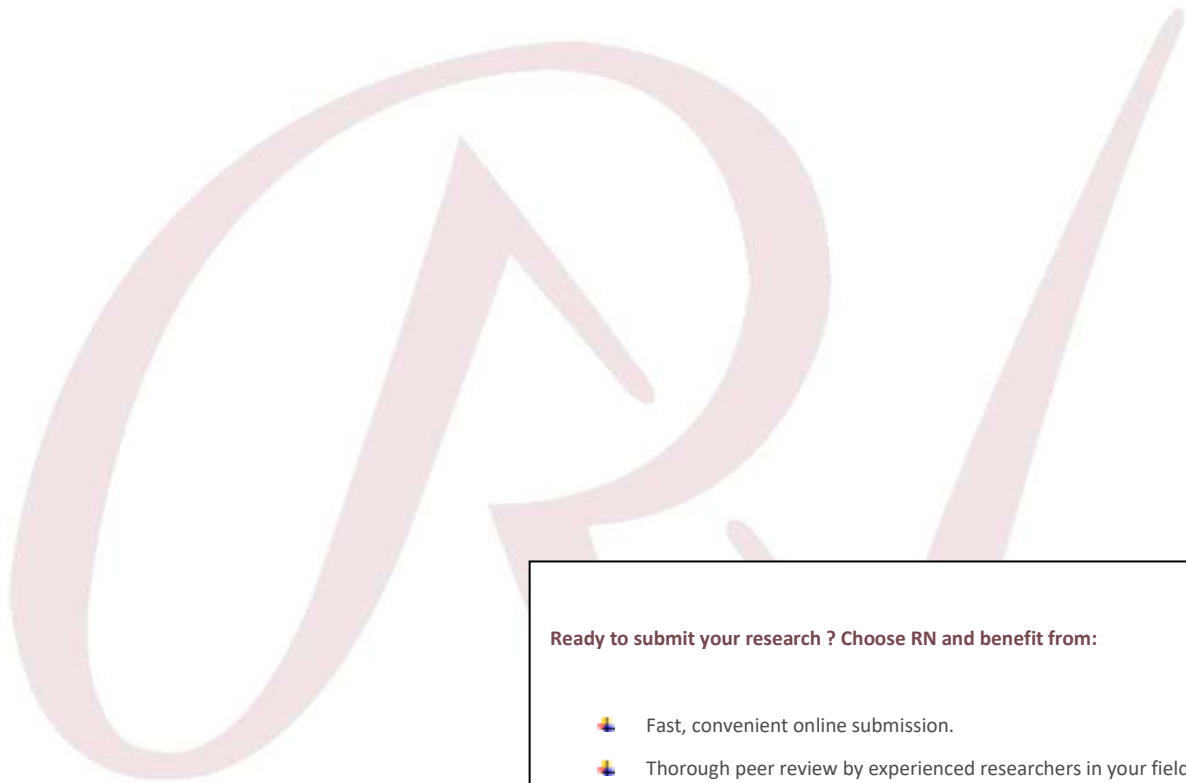

Figure 21: Asymmetric headgear forces.

References

Moore JC, Waters NE. Factors affecting tooth movement in sliding mechanics. Eur J Orthod 1993; 15: 235-241.

Smith RJ, Burstone CJ. Mechanics of tooth movement. Am J Orthod 1984; 85: 294-307.

Smith RJ, Burstone CJ. Mechanics of tooth movement. Am J Orthod 1984; 85: 294-307.

Burstone CJ, Koenig HA. Force systems from an ideal arch: large deflection considerations. Angle Orthod 1989; 59: 11-16.

Burstone CJ. The segmented arch approach to space closure. Am J Orthod 1982; 82: 361-378.

Hart A, Taft L, Greenberg SN. The effectiveness of differential moments in establishing and maintaining anchorage. Am J Orthod Dentofacial Orthop 1992; 102: 434-442.

Bills DA, Handelman CS, Begole EA. Bimaxillary dentoalveolar protrusion: traits and orthodontic correction. Angle Orthod 2005; 75: 333-339.

Hussels W, Nanda RS. Effect of maxillary incisor angulation and inclination on arch length. Am J Orthod Dentofacial Orthop 1987; 91: 233-239.

Sangchaream Y, Ho C. Maxillary incisor angulation and its effect on molar relationships. Angle Orthod 2007; 77: 221-225.

Carlsson R, Ronnermann A. Crown root angles of upper central incisors. Am J Orthod 1973; 64: 147-154.

Proffit WR, Fields HW, Ackerman JL, Sinclair PM, Thomas PM, Tulloch JFC. Contemporary orthodontics. St. Louis: Mosby-Year Book 1993.

Droschl H. The effect of heavy orthopedic forces on the maxilla in growing Saimiri sciureus (squirrel monkey). Am J Orthod 1973; 63: 449-461.

Baumrind S, Korn EL, Isaacson RJ, West EE, Molthen R. Quantitative analysis of the orthodontic effects of maxillary traction. Am J Ortrhod 1983; 84: 384-398.

Henriques JFC, Martins DR, Almeida GA, Ursi WJS. Modified maxillary splint for Class II, division 1 treatment. J Clin Orthod 1991; 25: 239-245.

Thurow RC. Craniomaxillary orthopedic correction with en masse dental control. Am J Orthod 1975; 68: 601-624.

Firouz M, Zernik J, Nanda R. Dental and orthopedic effects of high-pull headgear in treatment of Class II, division 1 malocclusion. Am J Orthod Dentofacial Orthop 1992; 102: 197-205.

Malmgren O, Omblus J. Treatment with an orthopedic appliance system. Eur J Orthod 1985; 7: 205-214.

Lahaye MB, Buschang PH, Alexander RG, Boley JC. Orthodontic treatment changes of chin position in Class II Division 1 patients. Am J Orthod Dentofacial Orthop 2006; 130: 732-741.

Brosh T, Portal S, Sarne O, Vardimon AD.Comparing 2 asymmetric headgear systems. Am J Orthod Dentofacial Orthop 2005; 128: 68-77.