A Concept and Classification of Centers of Rotation and Extraoral Force Systems

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To effectively employ extraoral force systems or headgear, it is necessary to consider four essentials. They are: 1) centers of rotation, 2) direction, 3) force (magnitude), and 4) duration. If any one of these considerations is neglected, the delivery system will be ineffective and unpredictable. It is perhaps because of these variables that clinicians have met with varying results and techniques.

Christiansen and Burstone[2] have illustrated the importance of biomechanics in their studies of incisor centers of rotation. When a single simple force is applied to a body, it moves by translation (bodily movement), rotation (tipping) or a combination of both depending upon the perpendicular distance between the force vector and the center of resistance of the body. If the force passes directly through the center of resistance, the body will translate. If the force does not pass through the center of resistance, a moment arm is created which is the shortest perpendicular distance between the force vector and center of resistance and causes rotation. In this instance the center of resistance still moves in the direction of the force and the body will also rotate as it moves.

The degree of rotation or translation is determined by the location of the instantaneous center of rotation. If the center of rotation is near the center of resistance, the body will predominantly rotate. Conversely, as the center of rotation approaches infinity, the body will predominantly translate. Location of the instantaneous center of rotation is inversely related to the perpendicular distance of the force vector to the center of resistance. As the perpendicular distance of the force vector to the center of resistance increases, the center of rotation approaches the center of resistance and vice versa. If multiple force vectors are involved such as retraction forces and base arches, vector analysis can reduce them to a single resultant force vector from which a moment arm can be figured. This in turn determines the instantaneous center of rotation for the system involved. By adding free vector couples to the system, i.e., torque, additional control of the instantaneous center of rotation is possible but will not be a factor in this discussion of headgears.

A simple demonstration will quickly illustrate the above principles. Place a textbook on a flat surface such as a desk top. Lay the book flat with the bound side of the book at the desk edge for a reference line. Apply a force parallel to the desk top and against the bound side of the text with a pencil located so that the force is applied through the center of resistance of the text and perpendicular to it. By experimentation the exact center of resistance can be located and the text will translate with a center of rotation at infinity (Fig. 1-top). It should be noted that the pencil force was applied somewhere near the middle of the bound side. Next, move the pencil contact halfway toward one end of the text and apply a perpendicular force. Note the change in the center of rotation (Fig. 1-center). Lastly, locate the pen-

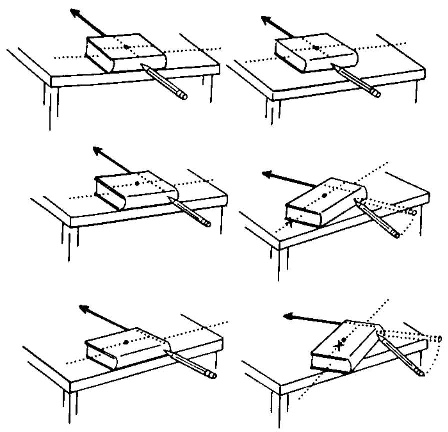

Fig. 1 A simple experiment to illustrate relationships between center of rotation (X) and variable perpendicular distances between force (pencil) and center of resistance (.). Top, translation - center of rotation (X) at infinity (∞) center of resistance (.). Center, rotation - center of rotation (X) at edge of book. Bottom, rotation - center of rotation (X) near center of resistance (.).

cil at the very corner of the book and apply force. The center of rotation will be located within the textbook near the center of resistance and the opposite corner of the text will move in the opposite direction (Fig. 1-bottom). By continued experimentation, various centers of rotation can be created merely by changing the perpendicular distance of the force (pencil) to the center of resistance of the text.

During headgear therapy utilizing facebows, authors[4,6,9,11,12,14] have suggested "raising outer bows" to prevent distal crown tipping or rotation of molars. The amount of "raising" has a direct effect upon the perpendicular distance of the force vector to the center of resistance which in turn determines the instantaneous center of rotation of the molar movement.

Because of skeletal variations[3,7,18] the importance of headgear force direction has been suggested by numerous authors.[1,5,11,12,16,17] The direction of the headgear force system can be adjusted for extrusion, intrusion, mesial or distal movement with in-between combinations. Since the vertical height of the upper molar is so important[7] during diagnosis and treatment planning, it is essential to consider direction in headgear force design.

Force initiates movement and duration or time determines how long it will be acting and when. Optimum forces and time schedules have not been documented and suggested forces range from a few ounces[15] to several pounds[1,5] or as much as the patient can stand.[8,10] Timing of treatment varies from the mixed dentition to adulthood and optimum numbers of hours from night wear[10,14,15] to twenty-four hours.[1]

Since so many variables are involved with headgear therapy, quantitative investigations have met with frustration. However, during pilot studies using cephalometric laminagraphic sectioning it was apparent that quantitation efforts were hindered due to varying centers of rotation of the maxillary molars. While force, duration and direction were being controlled, the molars were moving with varying degrees of rotation and translation. It was, therefore, reasoned that centers of rotation are of fundamental importance in headgear utilization and force delivery.

It became clear that just "raising" or "lowering" outer facebows was too simplistic and that varying centers of rotation were being created without proper concern for their locations.

This study was designed to investigate the relationship of direction and position of headgear force vectors and instantaneous centers of rotation utilizing laminagraphic sectioning techniques. A simple model was also designed to help correlate mechanics with the biological system. From the information obtained, a concept of classification and design is proposed to communicate and deliver more effective headgear force systems. Additional studies on force and duration will be published later.

Methods and Materials

Fifteen patients, aged 11-16 years, exhibiting end-to-end or Class II molar relationships were selected for headgear therapy. Appliances consisted of banded maxillary first molars with .045 extraoral tubes and conventional extraoral facebows. Forces were applied to the facebows in various directions using either elastics or elastic strap material. After six months, fully banded appliance therapy was initiated utilizing multiple stranded, light, round wires for preliminary bracket alignment. None of the archwires were tied back or stopped. All patients had cephalometric laminagraphs through the buccal quadrant exposed at the beginning of headgear therapy and 2, 4, 6, 8, and 12 months later. In addition, after four months, routine lateral headplates were made with facebows in place in both activated and passive positions. Measurements of headgear force to the nearest ounce were recorded at each appointment using a dontrix guage. Patients' appointment forms were charted to record all treatments, hours of wear, and appliance changes.

Six patients, aged 11-13 years, with Class II molar relationships were selected for controls. They received no appliance therapy and had cephalometric laminagraphs exposed at intervals similar to those stated for the headgear group.

Tracings were made of all laminagraphs and headplates. Landmarks traced consisted of the internal meatus, condylar fossa and eminence, greater wings of the sphenoid bone, roof of the orbit, pterygoid maxillary fissure, maxillary tuberosity, maxillary second bicuspid, and all maxillary molars present. Axes for the teeth were established on beginning tracings and transferred individually to progress tracings. The tracings were placed on the reverse side of millimeter ruled graph paper and a pin hole punched through the apical and occlusal terminals of the axes lines. The pin holes were connected on the ruled side with colored axes lines. Each succeeding tracing was oriented on basilar landmarks and pin holes punched. Each set of pin holes was connected by a different colored line. The beginning and last tracings were left on the reverse side of the graph paper for visual assessment of the year's changes. On the millimeter graph paper, successive colored lines indicated the relative movement of the teeth's axes throughout the period of the study.

The lateral headplate was traced, the headgear facebow outlined, and its force vector drawn. This was transferred to the graph paper via maxillary first molar superimposition. A line was drawn on the graphed side indicating the relationship of the headgear force vector to the axis of the first molar. The fifteen patients with headgear force vectors superimposed were analyzed for centers of rotation at the fourth month. They were categorized as to clockwise or counterclockwise rotation or translation. Approximate centers of rotation were established using visual methods. Subjective assessments of additional tooth movements were also noted.

An experimental model was designed to simulate headgear mechanics. This consisted of a plywood outline replica of an upper first molar and heavy wire to simulate the facebow. Several different force distances relative to the center of resistance were designed so that, when a force was applied via

TABLE 1
Effects of headgear systems on fifteen patients with respect to the direction of the resulting molar movement

Moment	Force	No. Pts.	Center of Rotation
Counter-clockwise	Force one half distance from trifurcation to apex	2	Beyond crown
	Force at a distance equal to apex-trifurcation distance	2	Crown
	Force at twice the apex-trifurcation distance	4	Near center of resistance
None	Force through trifurcation	3	Infinity
Clockwise	Force one half distance from trifurcation to crown	1	Beyond apex
	Force at a distance equal to trifurcation-crown distance	3	Apex
	Force at twice the trifurcation-crown distance	0	Near center of resistance

an elastic, various centers of rotations could be observed. These movements were analyzed similar to free body mechanics with friction an evenly distributed variable.

Results

Of the fifteen headgear patients three exhibited translation with the force vector passing through the trifurcation area. The centers of rotation are shown in Table 1.

The theoretical center of resistance area or trifurcation of the molars moved in the direction of the headgear force. The instantaneous center of rotation approached the center of resistance as the distance of the force vector from the center of resistance increased. The control group exhibited a composite movement of the molar axis in an occlusal and mesial direction. The crown moved mesial more than the apex while it erupted and the direction of movement was always constant while the rate was not (Fig. 2).

Unerupted bicuspids erupted distally as the molar moved distally. Likewise erupted bicuspids also moved distally. Second molars were affected depending

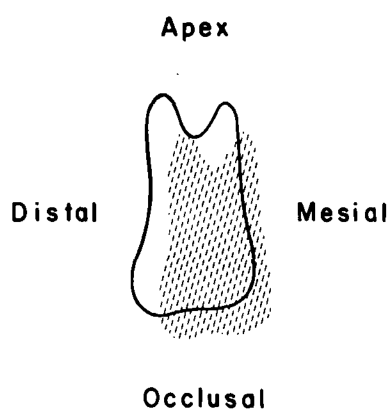

Fig. 2 Mean movement of upper first molar in six control patients.

		Occlusal	Mesial
apex	range	0.6 to 2.4 mm	0 to 2.0 mm
	$\bar{x}$	1.6 mm	1.1 mm
crown	range	0.6 to 2.4 mm	0 to 2.0 mm
	$\bar{x}$	1.6 mm	1.5 mm

Average age = 12.01 years
Range 11.25 to 13.25 years
Ave. Mand. Plane 35.6°
Range 29° to 45°

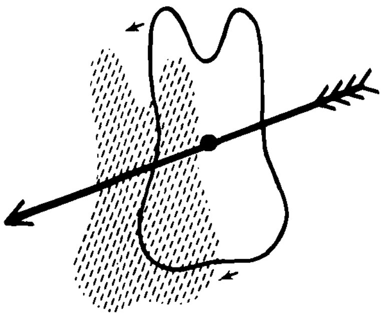

Fig. 3 Translation with a center of rotation at infinity.

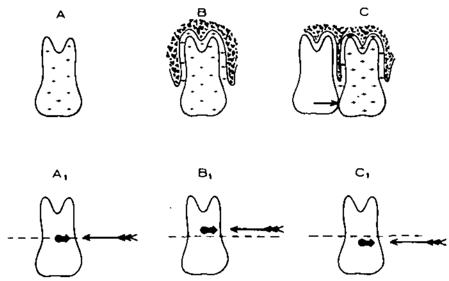

Fig. 4 A illustrates free body and its points of resistance. A_1 illustrates a composite resistance point reflecting a concentration of all resistance. B illustrates a system and its multiple points of resistance. B_1 illustrates the composite. C illustrates another system and C_1 its composite resistance point.

upon the amount of eruption they had completed and movement of the first molar. The crown and apices of the second molar responded directly to the movement of the contours of the first molar. If the second molar was erupting, its crown moved occlusally following a path of least resistance. If the crown of the first molar moved distally, it forced the second molar distally whether erupted or not. The third molar was also affected similarly. It moved distally as the second molar moved into it. The tuberosity area increased to accommodate the distal movement of the third molar.

In three instances of twenty hour headgear wear there was an indication of increases at the posterior border of the maxilla. However, no changes were ever observed in basilar areas. Correction of Class II molars to Class I relationships occurred by anterior growth displacement of the mandible, by distal movement of the maxillary molar, or a combination of both.

Erupted second molars in contact with first molars created a resistance to distal movement. This, in effect, altered the position of the center of resistance of the first molar. In patients with fully erupted second molars it was noted that the headgear force vector that caused translation was closer to the crown rather than at the trifurcation.

Discussion

When a force is applied to a body, the body resists the force (Newton's third law of motion). If it is a free body this resistance to movement can be reduced to one point called the center of resistance. A force directed through the center of resistance will translate the body (Fig. 3).

A tooth resists movement in a similar manner (Fig. 4). Resistance to movement comes from the periodontal membrane, the alveolus and adjacent contacting dental units, as well as the tooth itself. As force is applied to this system, the various resistances are brought to bear. If all the separate resistances are analyzed, they could be reduced to one point of resistance through which a force could be directed to cause translation. This point of resistance in the dental system that promotes translation is called the center of resistance.

A dental system because of its biological nature will vary. As these variations of the periodontal membrane, alveolus and adjacent dental units occur, so will the center of resistance vary. In everyday clinical orthodontics the orthodontist is adjusting his force delivery systems relative to centers of resistance. When translation of the dental unit occurs, his force has been directed through the center of resistance.

Due to anatomical limitations, force systems cannot be directed through the center of resistance of dental units in a simple manner. That is to say that orthodontic attachment mechanisms are somewhat removed from the center of resistance. How then are forces directed through the center of resistance to cause translation?

Tipping or rotation of the dental unit is easy since the attachment mechanism for the force delivery is located so that the force does not pass through the center of resistance.

In order to translate, other vectors must be added to the force system. Two common methods are usually employed. One is to add a couple or torque and the other is to adjust the dental attachment unit (bracket) by adding additional framework to the system.

A couple is defined as two equal and opposite forces acting in the same plane. A couple is also a free vector which means that it causes rotation about the center of resistance regardless of its point of application on a body. Torque in an edgewise wire is a common example of this principle. By adding sufficient couple to a force system that is not directed through the center of resistance, a proper ratio between the force and couple can be established to cause translation.

Pure rotation or tipping occurs when the center of rotation and center of resistance are at the same point. Pure translation occurs when the center of rotation is at infinity. Pure rotation requires a couple or two opposite and equal forces. Pure translation requires a single force acting through the center of resistance or a single force not through the center of resistance but with a properly balanced couple.

A single force not acting through the center of resistance and without a couple creates translation and rotation. The center of resistance translates but, in addition, the body will rotate about the center of resistance. There also occurs an instantaneous center of rotation for the system somewhere between infinity and the center of resistance. This center of rotation is related to the perpendicular distance between the force vector and the center resistance.

The framework of the attachment mechanism can be adjusted by extension arms so that when the force is applied, it, in effect, will be traveling through the center of resistance or at any distance from it that is desired. The facebow is a good example of this method. While the framework of the facebow may take on many designs and points of attachment to the tooth, the effect on the dental unit is ultimately only related to the shortest perpendicular distance between the force vector and the center of resistance.

Fundamental physics teaches that the shortest perpendicular distance between a force vector and the center of resistance of a body determines the center of rotation. Figure 5 illustrates these principles as they apply to headgear systems. Regardless of the design of the facebow or "J" hook, the body (tooth) reacts to the force system of the headgear that is computed by figuring the shortest perpendicular distance from the force vector to the center of resistance. This distance dictates how the tooth moves and, more specifically, where the instantaneous center of rotation will be (Fig. 6).

While positions of molars undergoing extraoral headgear treatment may change, the source of the extraoral force usually does not. The effect of

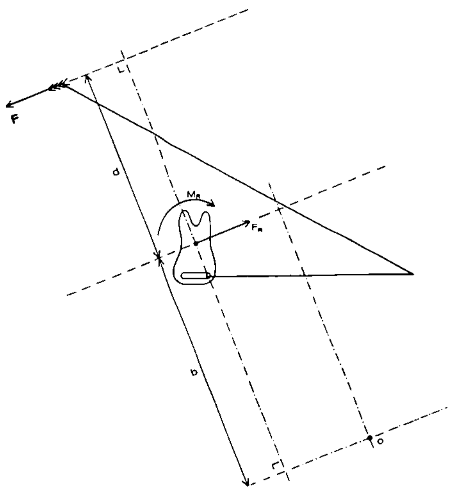

Fig. 5 In order to determine the moment in a headgear problem, choose any point (O) and determine the moments acting around it. ∴ Sum moments = $F_r{}^b - F(d+b) = F_r{}^b - F^d - F^b$. $F_r = F$ ∴ Σ moments = $-F^d$ or counterclockwise. Conclusion: Force times its perpendicular distance to the center of resistance equals the effective moment.

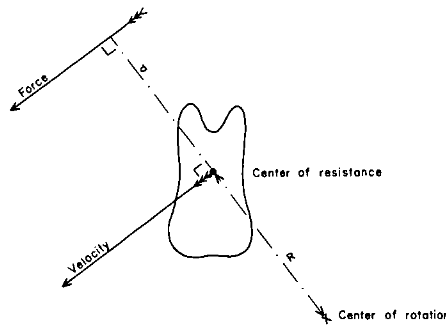

Fig. 6 Theory of center of rotation (a tooth is in pure rotation about the center of rotation). The instantaneous center of rotation lies on a line perpendicular to the velocity vector. The velocity vector lies on a line parallel to the force. Thus, the center of rotation lies on a line perpendicular to the force and passing through the center of resistance. A viscose model for our tooth system is suggested: F = force, V = velocity, X = angular speed, Y = viscosity coefficient, Z = viscosity, R = center of rotation, and d = distance.

$$R = \frac{V}{X},\ V = \frac{F}{Y},\ X = \frac{Fd}{Z}.$$

Substituting, R =

$$\frac{F/Y}{Fd/Z} = \frac{Z}{dY}$$

It may be possible in our tooth system that the ratio of Z to Y is a constant (k), thus the center of rotation (R) is inversely related to distance (d) and independent of force (F). $R = k/d$.

changing molar positions is most noticeable when movement involves rotation. Therefore, when the molar is rotating or tipping, the perpendicular distance between the headgear force vector and the molar center of resistance may change. When this distance is altered, the instantaneous center of rotation is also altered. It is possible through this phenomenon to reduce rotation tendencies as the molar begins to change position.

The perpendicular distance between the force vector and the molar center of resistance decreases creating instantaneous centers of rotation moving toward infinity. If carried far enough the molar would eventually translate if no other adjustments were made (Fig. 7). The textbook example in Figure 1 illustrates a constant center of rotation, as opposed to an instantaneous center of rotation, since the force vector (pencil) is directed in a constantly perpendicular direction to the text (therefore changing source of force). Headgears usually have constant sources of force direction with continuously changing force to center of resistance relationships and, therefore, have instantaneous centers of rotation.

The magnitude of the force in a free body system is unrelated to the center of rotation if acceleration is negligible. However, Christiansen[2] has shown that in a dental system there is a slight variation of the center of rotation due to magnitude. These variations occurred at magnitudes under 100 grams. Headgear systems are nor-

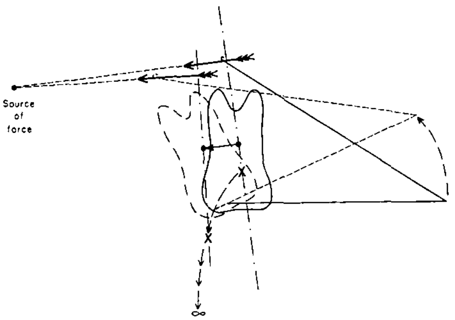

Fig. 7 Illustrates changing centers of rotation with a constant source of force. As the molar rotates, the facebow rotates. The perpendicular distance between the headgear force vector and the molar center of resistance decreases causing a migration of the center of rotation toward infinity.

mally above this level and for the present paper it will be assumed that magnitude is unrelated to center of rotation. Magnitude may be related only in the sense that increases cause more deformation of the facebow framework which may alter the force to center of resistance distance and hence alter the center of rotation.

It is apparent from this study that movement of the center of resistance and the center of rotation of the molar are extremely sensitive to the location and direction of headgear force application. Not only the headgear but also other external forces such as base arches, adjacent teeth and occlusal forces from opposing teeth affect headgear response. Base arches, for instance, have extremely long lever arms and can create large moments on the first molars (Fig. 8). Very often headgears are worn only part time, while base arches are acting continuously. It is quite possible to cancel the effect of the headgear moment entirely and even cause an opposite rotation on the molar than that which would be predicted by analysis of the headgear mechanics alone.

Fully erupted second molars create

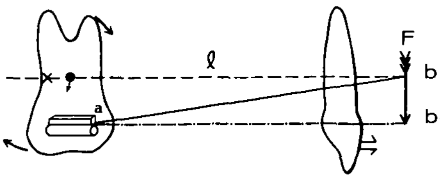

Fig. 8 (F) x (l) = moment created on molar by activation (b to b_1) of base arch (a-b). A center of rotation (X) is created very near the molar center of resistance(.).

a contact at the distal of the molar crown which can cause a mesial force or resistance which will alter the moment system on a first molar (Fig. 4c-c_1). The best example of this is shown when a force is applied distally through the center of resistance; one expects translation, but the erupted second molar creates a resistance acting in the opposite direction with a very effective counterclockwise moment. Thus, the first molar would tip distally, apex ahead of crown. In effect, erupted second molars alter the center of resistance of the first molar system in the direction of the crown. Unerupted second molars may less frequently create resistance since there is no contact with the first molar. The second molars do, however, move distally in response to the distally moving first molar and move as biomechanics would predict that they should.

The third molars also respond to distal movement of the first molar as it affects second molar movement. The third molar moves distally in response to distal movement of the apices of the second molar. Overlying this is the eruption of the third molar. It tends to follow the contours of the second molar. Increased tuberosity growth occurs to accommodate the distally moving third molar.

In several cases of very intensive headgear wear, the laminagraphs indicated increases at the posterior border of the maxilla. None of the patients exhibited changes beyond this area into the basal areas of the skull. It appears that this posterior increase occurs with intensive molar apical movement in the direction of the pterygoid maxillary fissure. The laminagraph may actually be showing a bulging of the maxilla lateral to the fissure. More precise sectioning in this area will have to be done to better explain this change.

Second bicuspids, whether erupted or unerupted, moved or erupted distally corresponding closely to the movement of the first molar crown. Since this is contrary to its normal path or eruption, it suggests that some type of interdental fiber connection may be present.

Intrusive movements did not cause intrusive movements of adjacent teeth unless connected by appliances. An erupted second molar should be banded if intrusive headgears are used, otherwise the second molar will remain at the original occlusal plane or continue to erupt. This phenomenon suggests a complicated interplay of occlusal forces, freeway space, and interdental fibers that react differently to horizontal and vertical forces.

Correction of Class II molar relationships occurred by distal movement of maxillary molars, retardation of maxillary growth, mandibular growth displacement, and anchorage loss in the lower molar area. Favorable combinations of all of these allow for very rapid Class II correction. Conversely, singular action of these items will correct the Class II molar relationship less rapidly. Certainly cooperation of the patient is a keystone to the successful employment of headgear. If the headgear is adjusted properly, as to moment, center of rotation, and force direction, correction of Class II molar relationships should occur. The amount of distal movement can be very dramatic, perhaps a whole molar width and, in spite of no growth, a correction will take place. Physical signs such as loose molars, spatial changes, tattered headgear harness, matted hair and grooved skull tissue are sure signs of cooperation. Least reliable is the patient's or parent's word. Future studies will attempt to quantitate and correlate force and hours with the type of molar movement. Insufficient data are presently available to describe optimum forces or number of hours of wear.

In the control group the average type of movement of the upper first molar relative to the basilar landmarks was mesial and occlusal. The axis of the average molar moved in an almost parallel mesial and occlusal direction. The direction of movement of the apex and crown was always mesial and occlusal. However, the rate of movement varied in that the apex did not always move an amount equal to the crown. Therefore, the molar varied from a movement whereby the crown moved mesially faster than the apex and vice versa, but still constantly in a mesial and occlusal direction. With the small control sample studied, no relationship between mandibular plane and molar movement could be detected. It was felt that this small sample was large enough to establish a consistent pattern of mesial and occlusal movement and it also agrees with previous authors'[8] reports of similar movement of upper first molars in untreated Class II individuals.

Varying centers of rotation of the model were illustrated by altering force distances. When the applied force was through the center of resistance, the model translated with the instantaneous center of rotation at infinity and the translation was in the direction of the force. As the perpendicular distance between the force and center of resistance increased, the instantaneous cen-

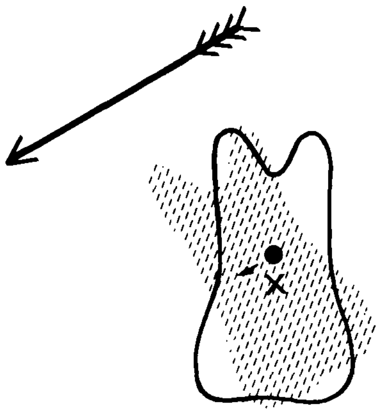

Fig. 9 A headgear force causing mesial movement of the molar crown and distal movement of the molar apices. The center of rotation (X) is very near to the center of resistance (.).

ter of rotation began moving from infinity toward the center of resistance. In general, as the perpendicular distance of the force to center of resistance passed through the apices, the instantaneous center of rotation was at the occlusal surface of the crown. By doubling the above perpendicular distance of the force from the center of resistance, the center of rotation approached very near the center of resistance and the crown and apex moved in opposite directions.

The movement of the crown and apex in opposite directions was shown by a number of headgear patients (Fig. 9). Clinically, these patients exhibited no correction of the Class II molar relationship. In fact, some had an increase in the severity of this relationship. This occurred in spite of faithful headgear wear. The problem was apparent. Their headgear force vectors were being delivered at too great a distance from the center of resistance. This produced a center of rotation near the center of resistance and consequently mesial movement of the crown. If long outer headgear bows are used, they must be adjusted very carefully so that the resultant force vector is not too far from the center of resistance of the molar. This will allow anticipated distal movement of the molar crown to take place. It must be remembered that the length of the outer facebow does not determine the moment on the molar, but that the perpendicular distance from the force vector to the center of resistance does. Figure 10 shows varying lengths of outer facebows all having the same effect, translation, on the molar.

Theoretically, if a force is directed through the center of resistance of a body, it will translate. In this experimental group three patients showed translation. The superimposed force system passed through the trifurcation of the molar in all three cases indicating that the center of resistance was located in this area. The other patients exhibited centers of rotation that would be compatible with a theoretical location of the center of resistance at the trifurcation.

The activated facebows corresponded to the correct force system rather than the passive facebows. For instance, in a routine cervical traction system with high outer bows, the outer facebow arms are pulled inferiorly as traction is applied. The force vector should be figured from the activated system. The critical factor is the perpendicular distance from the line of force to the center of resistance (Figs. 11a-c).

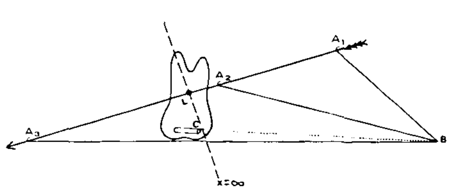

Fig. 10 Headgear facebows with varying outer bow lengths A_1, A_2, A_3. All create molar translation because the resultant headgear force vector passes through the center of resistance (.). The center of rotation (X) is at infinity (∝).

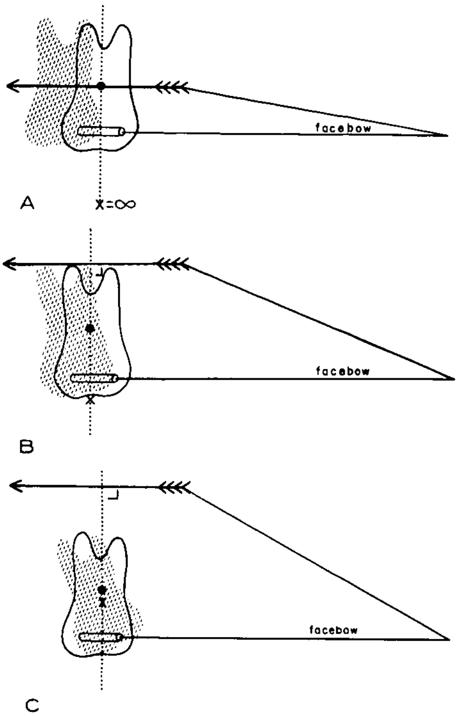

Fig. 11 The shortest perpendicular distance between the headgear force vector and the center of resistance (.) determines the moment arm and hence the center rotation (X). A) translation, B) translation of the center of resistance producing a center of rotation near the occlusal, C) mostly rotation producing a center of rotation (X) near the center of resistance.

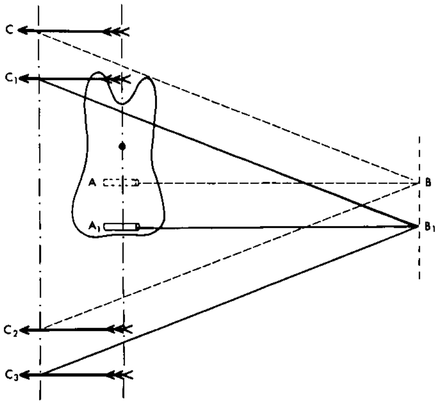

Fig. 12 Illustrates the effect of tube position variability with constant facebow design. Tube position A with facebow ABC creates more rotation or tipping than tube position A, with facebow A_1, B_1, C_1; if the same facebows were turned over then tube position and facebow A_1, B_1, C_3 would create the greater rotation. The outer bow should be positioned by facebow design while the headgear tube should be positioned for convenience.

Controversy regarding occlusal or gingival positioning of the headgear tube relative to the archwire should be placed in proper perspective. The ultimate effect of the tube position is to establish the location of the outer bow hook which ultimately determines the perpendicular distance of the force to center of resistance distance. Consequently, given two *identical* facebows, the headgear tube located gingivally will "raise" the outer bow hook relative to the molar center of resistance (Fig. 12). Conversely, given the identical position of the outer facebow hook and, therefore, a constant force vector to center of resistance distance, any position of the headgear tube on the molar crown will give the same center of rotation or molar movement (Fig. 13). The position of the headgear tube, therefore, should be established for convenience, since the type of molar movement is determined by the position of the outer bow hook which is controlled by the design of the facebow framework.

The molars responded to intrusion or extrusion depending upon the direction of the headgear force system. If the force was parallel to the occlusal plane, no extrusion or intrusion occurred. If the force was directed through the molar from a source below the occlusal plane, the molar extruded. If the force was directed through the molar from a source above the occlusal plane, the molar intruded. The response of the molar to the direction of the headgear force makes it imperative to consider extrusion or intrusion potential in the design of headgear systems. Consideration must be give to skeletal variations

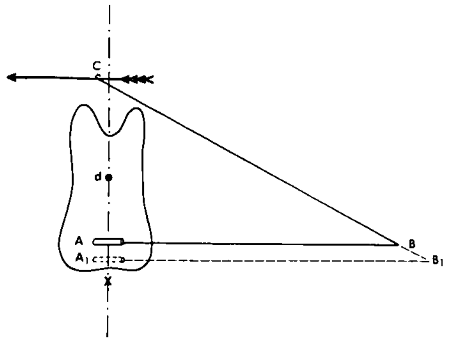

Fig. 13 Illustrates two different headgear tube positions A and A_1. Facebows A, B, C and A_1, B_1, C create identical centers of rotation (X).

Fig. 14 A cervical headgear with superimposed x-ray to show angle of headgear force to occlusal plane. The extrusive vector created is much greater than in patient in Figure 15.

when prescribing extraoral force systems.

After studying the effect of headgear therapy it became evident that descriptive terminology, as presently used, was often misleading in regard to actual molar movement. For example, straight pull headgear usually means a force directed at the lobule of the ear and connotes no extrusion of the molar. However, if the occlusal plane angle is quite steep, considerable extrusion may occur when none was intended (Fig. 14).

Likewise, cervical headgear usually assumes that extrusion will take place, but again the occlusal plane angle may be such that little extrusion occurs (Fig. 15).

The effect of moment arms has been suggested by numerous authors,[1,6,11,19] but not the effect on the center of resistance or center of rotation which is what really describes the movement of a body. High pull and occipital pull are other terms which mean different things to different clinicians. A simple means of classification was needed that would describe the type of movement, vector system, and direction of force.

A classification system was designed to describe the center of rotation of the molar relative to the perpendicular

Fig. 15 A cervical headgear with superimposed x-ray to illustrate minimum extrusion. The term "cervical headgear" does not describe direction of force adequately.

distance of the headgear force from the center of resistance and the direction of the headgear force. Based on the experimental model and laminagraphs with superimposed headgear force systems, five basic kinds of movement were observed, translation and four types of rotation. The center of rotation is located along an axis perpendicular to the line of force and passing through the center of resistance. By designating the direction of force by the hours of a clock, the movement of the molar can accurately be described. The main thing to remember in locating the center of rotation of the molar is that, as the perpendicular distance from the line of force to the center of resistance distance increases, the center of rotation approaches the center of resistance. For all practical purposes, as this distance approaches twice the center of resistance-apex distance, the center of resistance and center of rotation are essentially the same. Conversely, as the force to center of resistance perpendicular distance decreases, the center of rotation moves toward infinity. The position of the hook of the outer bow and source of the traction establishes the force vector from which the perpendicular distance to the center of resistance can be computed and designates one of the five types (Fig. 16). The *direction* of the force is identified by the clock hour which has 12 o'clock superior and always perpendicular to the occlusal plane and establishes mesial-distal and intrusive-extrusive proportions (Fig. 17). This system can be applied to "J" hooks relative to incisors or to complete dentitions. The latter have not had exact centers of resistance established, but are estimated to be in the second bicuspid root area.

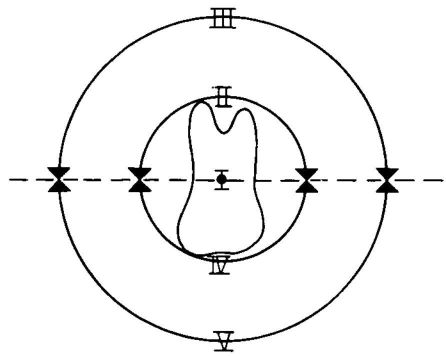

Fig. 16 Force vector to center of resistance. Radii for the classification system for the five types (I-V).

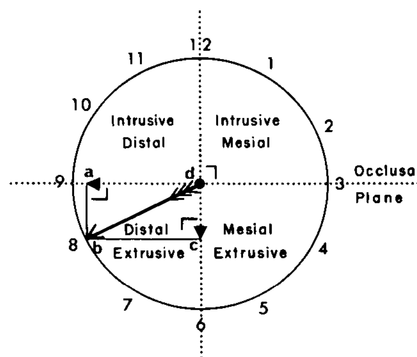

Fig. 17 Clock hours designate the direction of the headgear force vector relative to the occlusal plane (intrusive - extrusive) and the anteroposterior plane (mesial - distal). The force direction shown is 8:00 with a distal component of "ad" and extrusive component "dc."

The five types as they relate to maxillary molars are as follows: Type 1 (Fig. 18, left), the center of rotation is at infinity and the force vector is directed through the center of resistance or trifurcation causing translation. Type II (Fig. 18, center left), the force is superior to the center of resistance and at a radius equal to the apex-trifurcation distance and causes tipping with a center of rotation at the crown. Type III (Fig. 18, center), the force is superior to the center of resistance and at a radius twice the apex-trifurcation distance and causes tipping with a center of rotation near the center of resistance. Type IV (Fig. 18, center right), the force is inferior to the center of resistance and at a radius equal to the crown-trifurcation distance and causes tipping with a center of rotation at the apex. Type V (Fig. 18, right), the force is inferior to the center of resistance and at a radius twice the crown-trifurcation distance and causes tipping with a center of rotation near the center of resistance. Force systems falling in between are designated with a dash (—) between appropriate major types. In typing the various force systems, the shortest perpendicular distance or radius from the force vector to the center of resistance is utilized. Examples are given in Figure 19.

The type and direction of the headgear is determined during diagnosis and treatment planning. This information is then transferred to the patient by adjustment of the outer bow of the facebow and selection of the appropriate head strapping. The type and direction of desired molar movement will determine the position of the outer bow and the source of the headgear force system. Multiple headgear harnesses are available so that forces can be directed to the neck, through the ear, and to the back and top of the head. The amount of force and duration hopefully will be answered soon.

The variability of the orthodontically applied force systems throughout treatment suggests that headgear forces need to be constantly adjusted. Initial force systems are altered as treatment progresses, for instance, base arches, cuspid retraction, en masse retraction, intra- and intermaxillary elastics and torque systems, all applied at varying times throughout the treatment. To more easily adjust and balance moments and force systems on the molar via the headgear, this study suggests that an adjustable headgear would be beneficial. Sliding and interchangeable outer bows would allow for periodic adjustment of type and direction of headgear forces (Fig. 20).

Bending moments are created throughout the outer and inner bow of the facebow as traction is applied. One of the greatest bending moments is created at the junction of the facebow and molar tube attachment. Considerable bending and deformation can occur at this point with long term use and high force systems.

Figure 21 indicates a load deflection curve for round wire. The characteristics of a facebow that would best prevent bending and deformation are increased diameter and increased heat treatment or work hardening. The slope of a load deflection curve depicts stiffness, the steeper the slope, the stiffer the wire. As the stiffness increases, the deflection during a given activation is decreased. The less a facebow is deflected during activation, the more accurately the force type can be delivered to the tooth. The amount of force a given wire will support before exceeding its proportional limit can be controlled by heat treatment and work hardening. If a wire is too soft it deflects or takes a permanent set under too small a load. The ideal facebow wire should sustain clinical forces without permanent deformation. Present information[1] indicates that useful clinical forces range up to 48 ounces per side, therefore wire selected for facebow use should have minimum deflection and no deformation while sustaining such loads.

Facebows with inner and outer wire diameter of .072 inches were designed and .072 inches facebow tubes used for the molar attachment. By increasing the inner bow to .072 inches from .045 inches the stiffness (section modulus) of the wire was increased fourfold.[19] Permanent deformation was eliminated and deflection during loading was only one quarter as much as the .045 facebow.

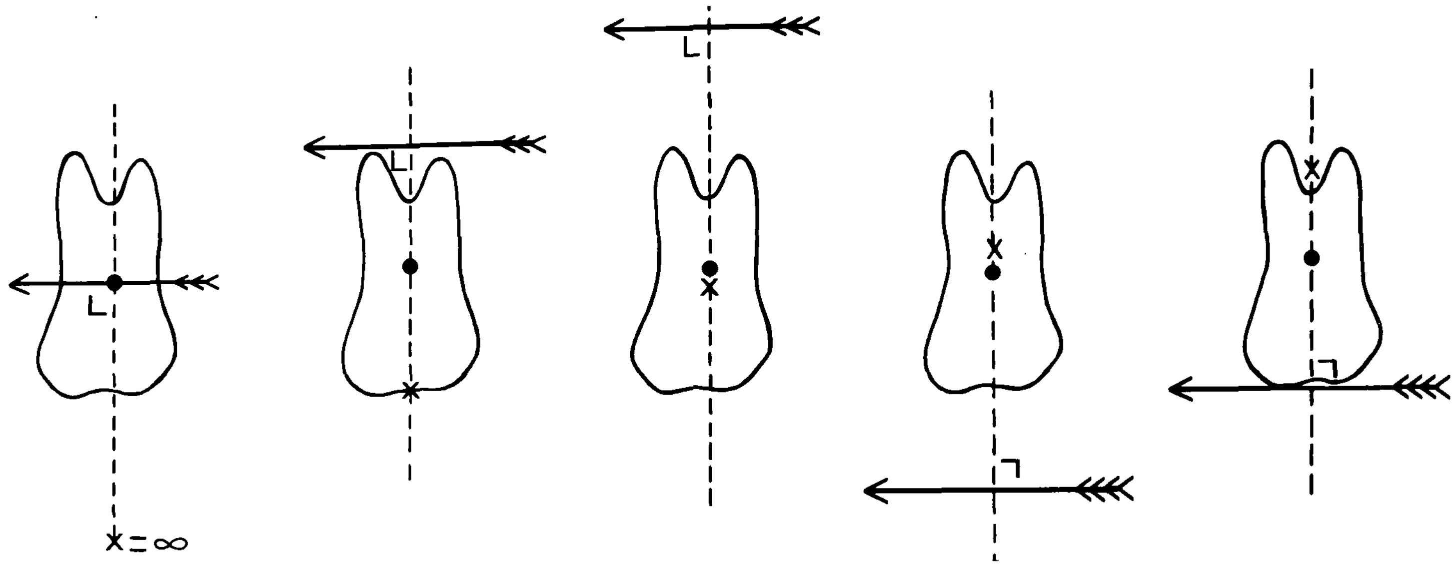

Fig. 18, left, A type I force vector through the center of resistance (.) at 9:00 produces a center of rotation (X) at infinity = translation.

Center left, A type II force vector through the apices at 9:00 produces a center of rotation (X) at the occlusal = rotation.

Center, A type III force vector at 9:00 at a distance twice the apex-center of resistance (.) distance with a center of rotation (X) near the center of resistance = rotation. The crown moves in the opposite direction of the apices.

Center right, A type IV force vector at 9:00 through the occlusal produces a center of rotation at the apex = rotation.

Right, A type V force vector at twice the occlusal - center of resistance (.) distance produces a center of rotation (X) near the center of resistance = rotation. The apices move in the opposite direction of the crown.

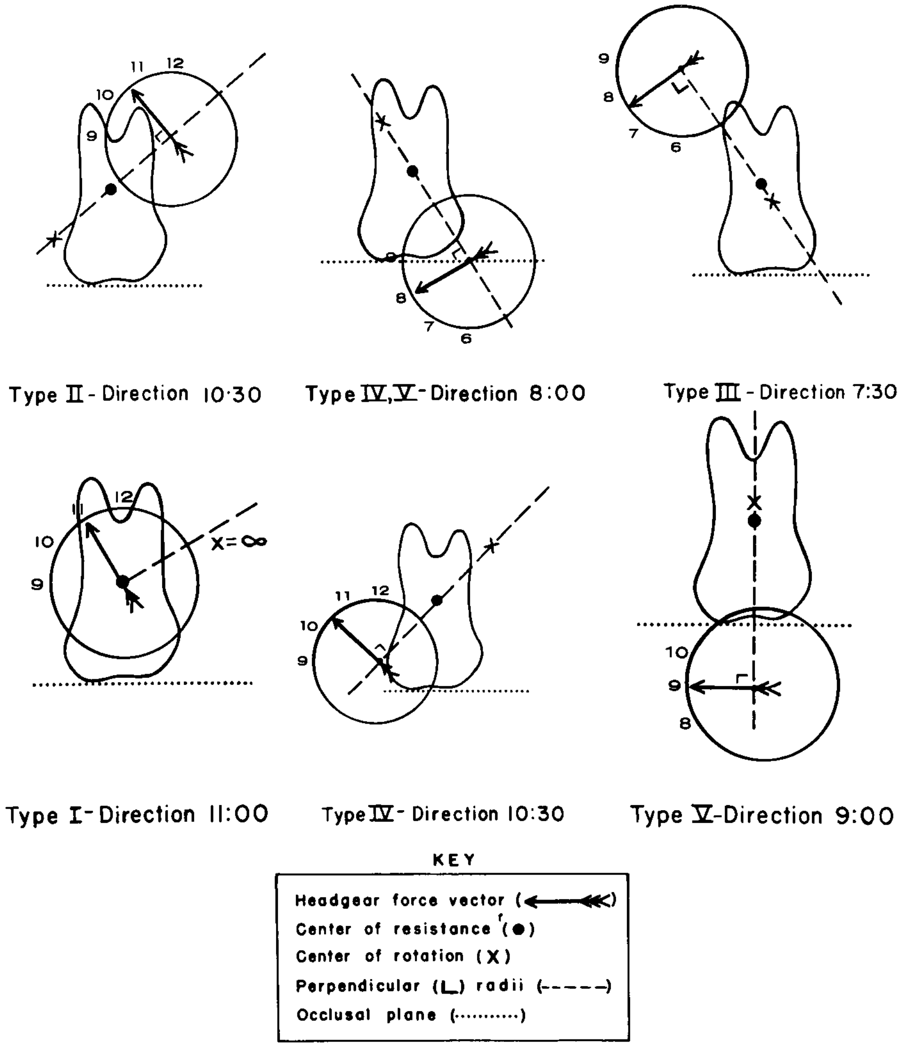
Type II - Direction 10:30
Type IV,V - Direction 8:00
Type III - Direction 7:30
X = ∞
Type I - Direction 11:00
Type IV - Direction 10:30
Type V - Direction 9:00
KEY
Headgear force vector
Center of resistance (●)
Center of rotation (X)
Perpendicular (L) radii (-----)
Occlusal plane (..........)

Fig. 19

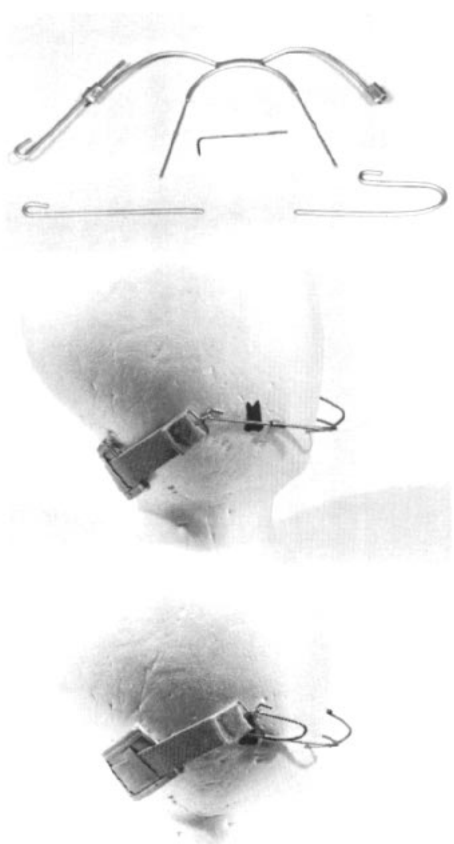

Fig. 20, top, Adjustable facebow mechanism. The outer bow hooks can be adjusted by sliding variously designed hooks into sleeve and locking in place.

Center, Adjustable facebow on mannequin adjusted to a type III - 7:30 direction.

Below, Same facebow as in Figure 20 center, adjusted to a type II - 7:30 direction by changing hook position.

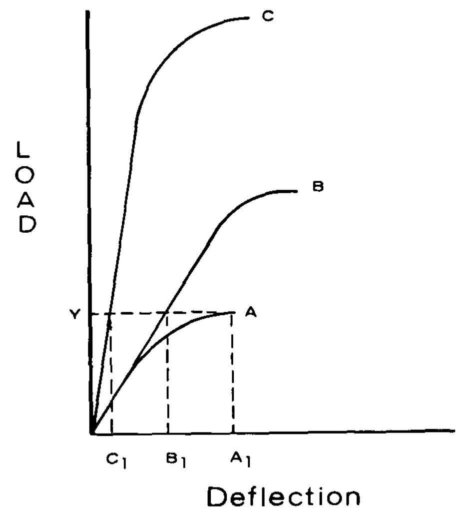

Fig. 21 A load deflection curve for same alloy round wires. Wire C has a larger diameter than wires A and B. It has greater stiffness as shown by the greater slope of its curve. Wires A and B are the same diameter hence have the same slope and stiffness. Wires A and B differ in their work hardening and heat treatment properties. Wire A is softer than wire B. With a given load, y, note the deflection characteristics of the three wires (C_1, B_1, A_1).

Summary and Conclusions

1. Variable centers of rotation can be created by altering perpendicular force vector distances to molar centers of resistance.
2. The center of resistance of the first molar was located within the trifurcation area.
3. Second and third molars moved distally in response to distally moving first molars.
4. Erupted and unerupted second bicuspids moved distally with distally moving first molars.
5. First molars were extruded or intruded according to the direction of the headgear force.
6. Second bicuspids and second molars were not intruded as intrusion of first molars occurred unless attached with appliances.
7. No changes in basal landmarks were observed due to extraoral therapy.
8. A headgear classification system based on the force to center of resistance distance and direction was presented.
9. A prototype adjustable facebow was suggested.

10. In order to minimize facebow deflection during loading, use of the largest diameter facebow and tubes available was suggested.

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