A Mechanical Appraisal of the Kloehn Extraoral Assembly

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The importance of extraoral force in orthodontics, though overlooked for many years, is now fully appreciated by most orthodontists. One of the systems frequently used is that which was devised and popularized by Kloehn.[1-4]

An over-all understanding of the treatment potential of this appliance can readily be gained by an understanding of the mechanical principles involved in its clinical application. Haack[5] emphasised that a true comprehension of biological response to force action could not be achieved without first gaining an accurate knowledge of the force action involved.

Though physiological tooth movement is governed by biological laws, it is initiated and maintained by force. In applying this principle, biomechanics and biophysics have taken clinical orthodontics out of the ranks of empiricism and placed it in its rightful company amongst the true sciences.

It is the purpose of this paper to discuss the functional mechanics of the Kloehn extraoral assembly as it is manipulated to effect a variety of desirable tooth movements. The influence of the appliance upon growth direction will not be discussed.

The appliance consists of an inner and outer bow soldered together near the middle of the two bows. Force is delivered by a cervical elastic strap which hooks on to the ends of the outer bow (Fig. 1). The outer bow may be used in various lengths conveniently described as: 1) short, shorter than inner bow, 2) Medium, approximately

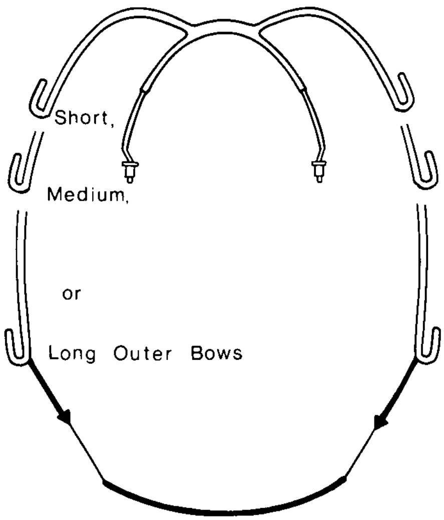

Fig. 1 The Kloehn inner and outer bow assembly illustrating variations in the length of the outer bow.

the same length as the inner bow and 3) long, longer than inner bow.

The assembly is adapted for each individual patient to permit the ends of the inner bow to engage in tubes attached buccally to bands on the teeth to which force is to be applied. Stops are placed on the inner bow mesial to the buccal tubes to allow force applied to the outer bow to be transmitted through the inner bow to the molar teeth. In the correctly fitted appliance the soldered joint should lie comfortably between the lips (Fig. 2). It is usually the upper first molars to which the appliance is attached, but in cases where the treatment plan prescribes it, other posterior teeth in the upper or lower jaw may be used. In

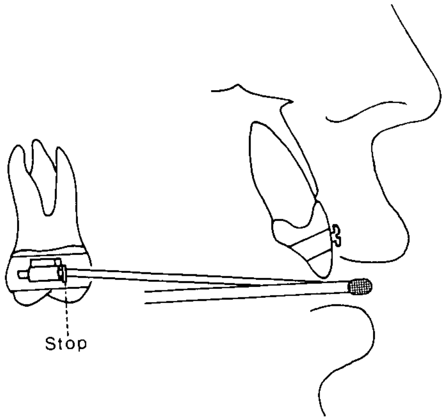

Fig. 2 Correct position relative to the lips of the joint between inner and outer bows.

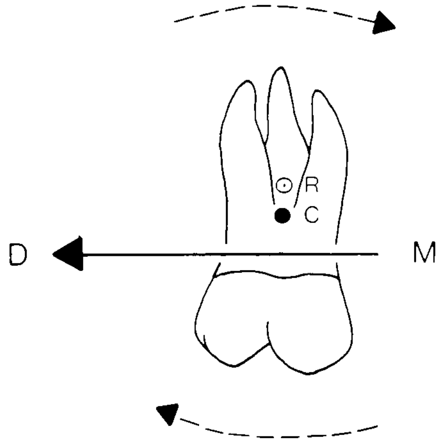

Fig. 3 Should the line of force not pass through the centre of resistance the tooth will tip about the centre of rotation (R).

this paper, however, the term molar will mean "upper first molar."

Basic Premises

The point of greatest resistance to movement of a tooth, or the centre of resistance (C) is in the middle third of the root near the junction with the cervical third, or approximately at the trifurcation of the roots, if the tooth is an upper first molar.[6,7,8]

When the line of action of an applied force passes through the centre of resistance no tipping of the tooth will occur. The tooth does, however, tip if the line of action of the force does not pass through the centre of resistance. This tipping takes place around a centre of rotation (R) whose position varies according to the relationship of the line of action of the force to the centre of resistance of the tooth.[9]

Should the line of action of a dorsally directed force pass occlusal to the centre of resistance, the tooth will tip distally (i.e., the crown will move distally and the root apex mesially). The centre of rotation (R) is located apical to the centre of resistance (Fig. 3). Should the line of action pass apical to the centre of resistance, the tooth crown will tip mesially and the root apex distally. The centre of rotation is now located coronal to the centre of resistance.

During this discussion the assembly will be regarded as rigid, although it is recognized that elastic deformation does take place when the appliance is activated, even with heavy wires used in its construction (.070″ outer bow, .050″ inner bow). The site of the point of origin of the force is considered to be relatively constant for each patient, since the neckstrap finds a position of anatomical convenience on each individual (Fig. 4). This point is always below the centre of resistance of the upper first molar.[9,10,11]

For convenience, the force system involved is considered as being active in three mutually perpendicular planes.

a. Sagittal, in which the distal or dorsal force component acts.

b. Coronal, in which the vertical component acts.

c. Occlusal, in which the lateral force component acts (Fig. 5).

These planes are represented in two basic diagrams: a) lateral diagram, by which both dorsal/ventral and vertical force components may be illustrated

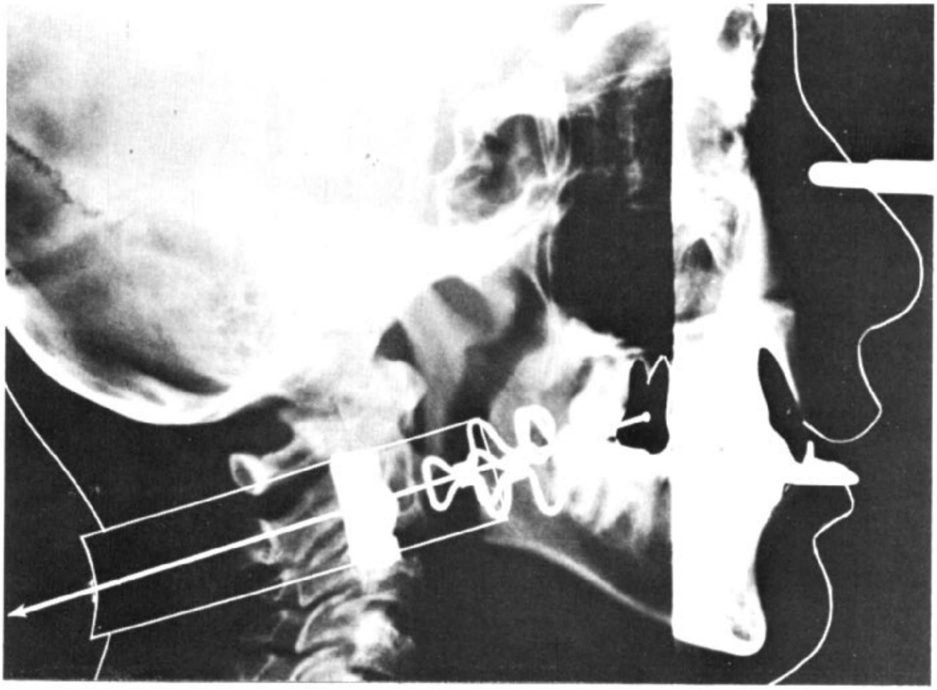

Fig. 4 Cephalometric head film with the Kloehn assembly in position.

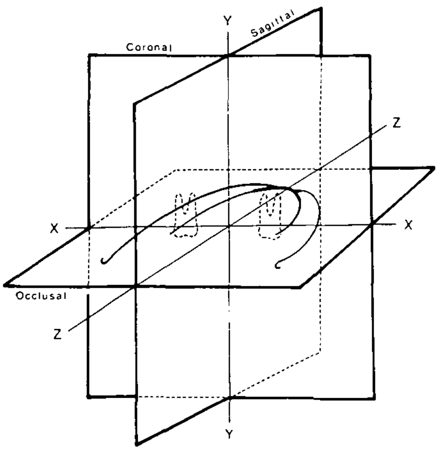

Fig. 5 The three planes in which the forces act.

(Fig. 2), the occlusal plane is represented as being horizontally disposed; b) occlusal diagram, by which both dorsal/ventral and lateral force components may be illustrated (Fig. 1).

Force System Represented in the Lateral Diagram

Tipping Forces

The line of traction of the force is that line connecting the point of origin of the force to the attachment hooks on the outer bow. The relationship of this line to the centre of resistance determines the resultant force components acting on the tooth.

It is clinically desirable that this relationship can be altered to control or to achieve tipping effects. The site of the point of origin of the force is relatively fixed by the position of the neckstrap, and the centre of resistance of the molar will likewise remain constant till the tooth has been orthodontically moved. Therefore the inclination of the line of traction may be altered only by variations in the position of the outer bow hooks. These alterations can be achieved by varying the length of the outer bow (Fig. 6), the angulation between the inner and the

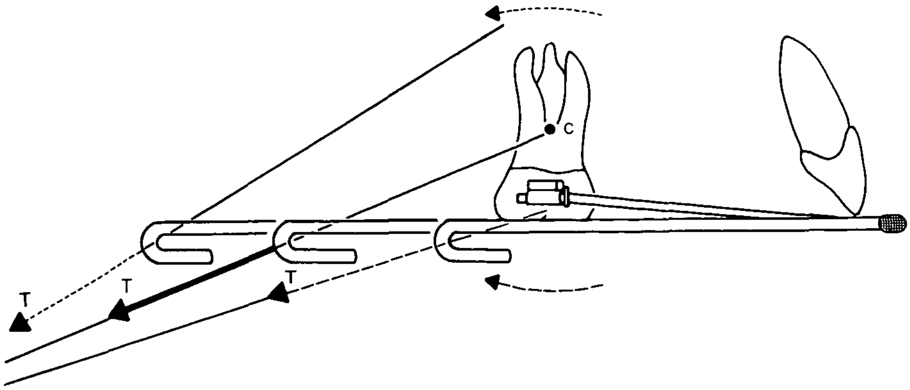

Fig. 6 Alterations in the length of the outer bow will change the line of action of the force (T).

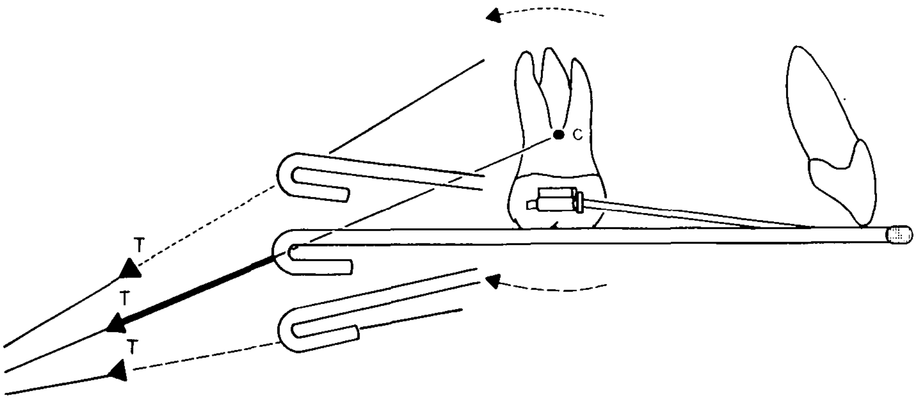

Fig. 7 Changes in the angulation between inner and outer bows will also change the line of action of T.

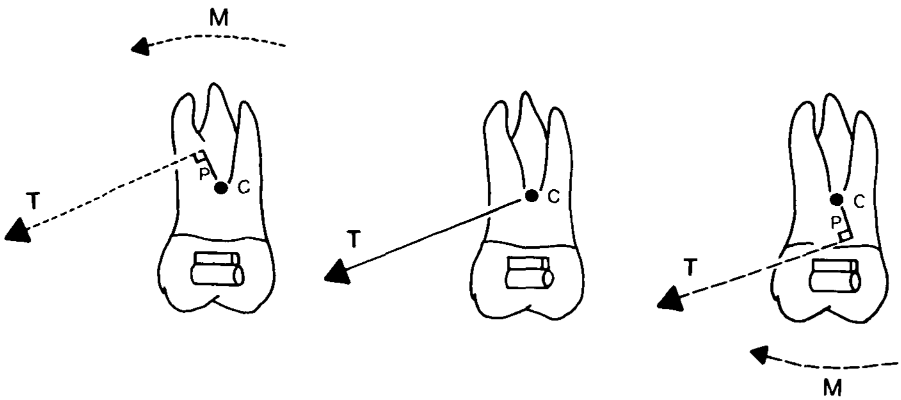

Fig. 8 Analysis of the tipping forces.

outer bows (Fig. 7) or variation of both length and angulation of the outer bow.

The very short outer bow is not versatile when used in conjunction with a cervical strap, since it is then not possible to adjust the appliance to achieve an inclination of the line of traction which passes through or above the centre of resistance of the tooth. Hence, if the appliance is assembled this way, it is limited to producing a distal crown tipping movement only with an extrusive component. The shape of the outer bow in itself has no effect if the relationship of the hook to the site of origin of the force remains unaltered.

The tipping force is analysed in Figure 8. M is the moment producing the tipping; T is the tension in the neckstrap; P is the perpendicular distance from the centre of resistance to the line of traction.

$$M = T \times P$$

With T constant, the tipping force therefore increases when the outer bow is so adjusted that the line of traction is moved farther away from the centre of resistance of the tooth thus increasing P. When the line of traction actually passes through the centre of resistance, P is zero. Therefore no tipping moment will be present. To achieve this effect clinically, the point of origin of the force, the hook and the centre of resistance must all be in the same straight line.

Control of tipping is thus possible. The soldered joint should lie comfortably between the lips at rest at the beginning of treatment. At subsequent appointments this relationship is carefully inspected. A displacement toward the upper lip indicates mesial molar crown tipping, whilst movement toward the lower lip indicates distal crown tipping (assuming that no deformation of the appliance has taken place.) Any required adjustments to control tipping of the tooth may then be made.

Extrusive Force Component

When the point of origin of the force delivered by the cervical strap is below the centre of resistance of the tooth, an extrusive force component (E) will be present in most clinical applications. The magnitude of the extrusive force component is altered as adjustments are made to the facebow to control tipping. An increase in the inclination of the line of traction will result in a proportional increase in the extrusive component.

Figure 9A demonstrates a steep inclination of the line of traction producing a mesial crown and a distal root tipping. The extrusive component E is large. When the line of traction passes through C, i.e., when no mesial or distal crown tipping is produced, the extrusive component, however, is still present (Fig. 9B). An alteration of the appliance to achieve a distal crown and mesial root tipping will decrease the inclination of the line of traction. The extrusive force component E decreases (Fig. 9C) while the distal component D increases proportionately. A great variety of angulations and lengths of the outer bow may be used without altering the extrusive force component at all if the force applied is kept constant both in magnitude and direction (Fig. 10).

Mathematical Analysis

Consider angle O in the right angled triangle A B C (Fig. 11).

$$\sin \Theta = \frac{o}{h}$$

$$\cos \Theta = \frac{a}{h}$$

$$\tan \Theta = \frac{o}{a}$$

Where o = opposite side, a = adjacent side and h = hypotenuse. Now con-

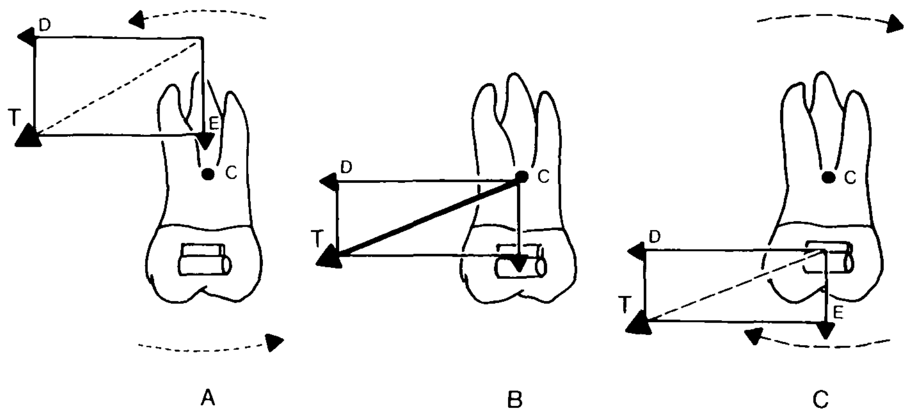

Fig. 9 The extrusive component is present with mesial crown tipping (A) no tipping (B) and also with distal crown tipping (C).

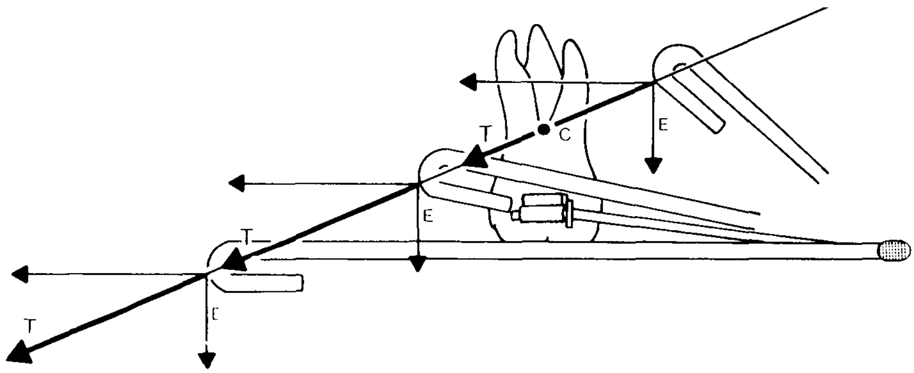

Fig. 10 Three combinations of length and angulation of the outer bow with no change in the direction of the line of traction thus keeping the extrusive component (E) constant.

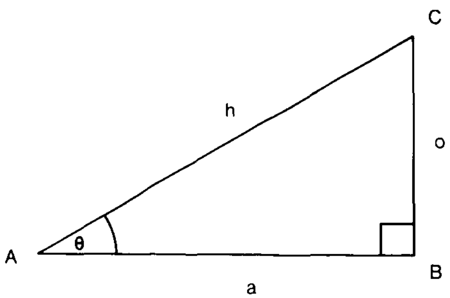

Fig. 11 A right-angled triangle with adjacent side (a), opposite side (o) and hypotenuse (h) as related to angle Θ.

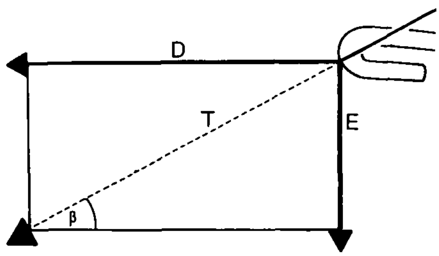

Fig. 12 Resolution of forces at the hook of the outer bow with dorsal component (D) and extrusive component (E).

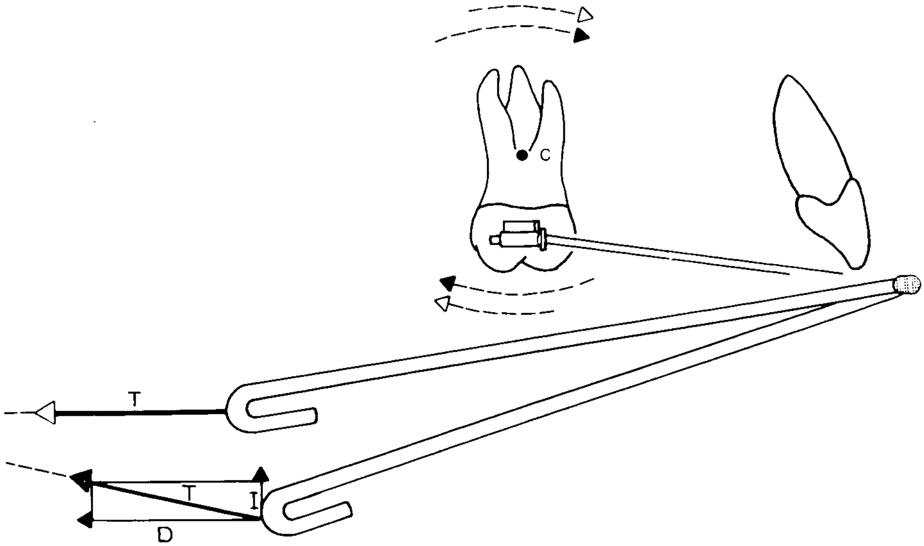

Fig. 13 If the line of traction is parallel to the occlusal plane, no extrusive force exists. Should it dip below the occlusal plane an intrusive force (I) becomes active.

sider angle ß in the parallelogram of forces depicted in Figure 12.

$$\text{Sin } ß = \frac{E}{T}$$

$$\therefore \quad E = T \sin ß$$

Assess now the situations where variables in the equation E = T sin ß are made constant:

A) If T is constant, E is directly proportional to sin ß. Hence the magnitude of the extrusive component may be affected only by alterations in the size of angle ß, i.e., in the inclination of the line of traction. As sin ß increases with increase in size of angle ß so then will E (Fig. 9).

B) If angle ß is constant, E is directly proportional to T, i.e., if the inclination of the line of traction is constant, the magnitude of the extrusive force component will have a direct relationship to the magnitude of the applied traction (Fig. 10).

C) When both T and ß are constant, E must also remain constant, i.e., a traction force constant in both magnitude and direction will produce a constant extrusive component (Fig. 10). When ß = O, E is zero, i.e., if the inclination of the line of traction is parallel to the occlusal plane, no extrusive force component exists (Fig. 13).

Intrusive Force Component

The vertical force component becomes intrusive (I) if the position of the hook on the outer bow is changed to a level lower than that of a plane passing through the point of origin of the force and parallel to the occlusal plane. This circumstance may obtain if the outer bow is long and is bent *considerably* downward (Fig. 13). This will be accompanied by strong distal molar crown tipping. It is not possible with the Kloehn assembly and cervical traction to achieve simultaneous intrusion and mesial molar crown tipping.

Dorsal Force Component

The dorsal force component (D) is clinically the most valuable. Consider the parallelogram of forces in Figure 12.

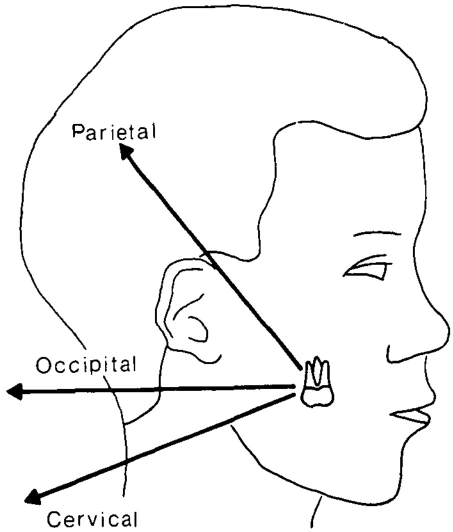

Fig. 14 The soldered inner and outer bow assembly may also be used in conjunction with forces of occipital or parietal origin.

$$\text{Cos } \beta = \frac{D}{T}$$

$$\therefore D = T \cos \beta$$

As ß increases so cos ß decreases, and thus D also decreases, i.e., an increase in the inclination of the line of traction will result in a decrease in the magnitude of the dorsal or distal force component. When ß = O° (Fig. 13), cos ß = 1 and thus D becomes equal to T.

In this situation the inclination of the force of traction is parallel with that of the occlusal plane. No intrusive or extrusive force components are present and the magnitude of the dorsal force component is equal to the magnitude of the applied force. Moments producing distal crown tipping are, however, very much in evidence.

Variations or Modifications

The Kloehn assembly normally incorporates the use of a cervical strap obtaining anchorage from the nape of the neck. The same inner and outer bow assembly may, however, gain extraoral anchorage from the back of the head (occipital) or from the upper part of the head (parietal) as shown in Figure 14. In comparing the effects of variation in the point of origin of the applied force, the basic laws still apply. The action of the tipping moments again depends upon whether the line of traction is above or below the centre of resistance.

Parietal traction has the origin of force well above the molar. Tipping can be controlled by a variation in the relationship of the inner and outer bows thus altering the inclination of the line of traction. An intrusive force component (I) is always present, together with the dorsal force component (D).

In occipital traction the point of origin of the force is such that the line of traction is more or less parallel to the occlusal plane. Slight intrusive or extrusive force components may be present under these circumstances. The tipping forces would likewise be minor.

The dorsal force component with cervical traction is usually accompanied by an extrusive component.

Force System Represented in the Occlusal Diagram

The occlusal diagram (Fig. 15) depicts the Kloehn assembly in the plane of the X-Z-axes (refer to Fig. 5) viewed from above. This system may be analyzed mathematically.

P and Q represent the reactive forces acting at the points of resistance of the left and right molars, A and B; the X axis is along a line joining A and B; the Z axis perpendicularly bisects line AB. T is the force delivered equally at each end of the elastic neck strap to hooks H_l and H_r α and ß are the angles made by the left and right lines of traction with the Z axis. The nape of the neck is represented as a segment of a circle with its centre somewhere along the Z-axis.

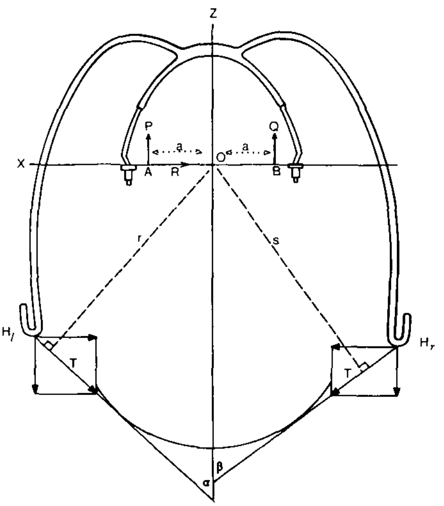

Fig. 15 Diagrammatic representation of the Kloehn assembly viewed from above.

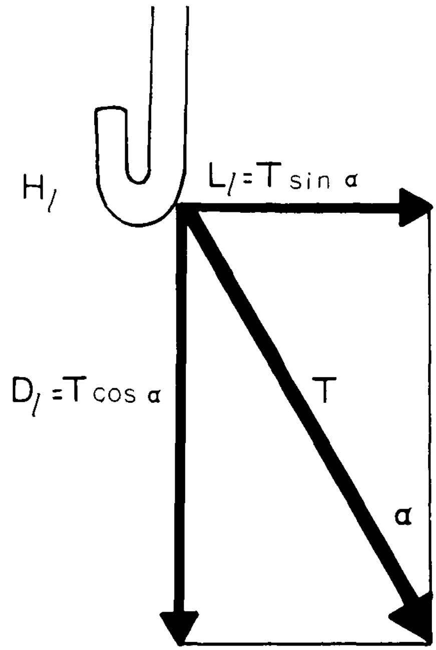

Fig. 15a Resolution of forces at the hook of the outer bow.

The forces acting at H_l (and H_r) may be resolved into lateral force components L_l (and L_r) acting parallel to the X-axis, and dorsal force components D_l (and D_r) acting parallel to the Z-axis. Resolution of the forces on the left side is depicted in Figure 15a thus:

$$L_l = T \sin \alpha$$

$$D_l = T \cos \alpha$$

Similarly on the right side we would have:

$$L_r = T \sin \beta$$

$$D_r = T \cos \beta$$

The lateral force components act in mutually opposite directions. If they are equal, they will cancel each other out. If they are unequal, however, a resultant lateral force will be produced. This force creates an equal and opposite lateral reactive force, which is depicted as R acting along the X-axis in Figure 15. A difference between α and ß will produce such a resultant lateral force component. Precise symmetry is unlikely to be attained under the usual practical clinical conditions and this is represented in Figure 15 where angle α is not quite equal to angle ß.

By applying the conditions of coplanar equilibrium to this system it is possible to derive these equations:

(1) $R = T (\sin \beta - \sin \alpha)$

(2) $P + Q = T (\cos \alpha + \cos \beta)$

(3) $Q - P = \frac{1}{a} T(s-r)$ where s and r are the perpendicular distances from point O to the lines of traction on the right and left sides, respectively.

ANALYSIS

From equation 1: a lateral displacing force will be present when angle α does not equal angle *ß*.

From equation 2: since the cosine of an angle decreases from a value of 1 at 0°, to that of 0 at 90°, an increase in angle α and/or *ß* will decrease the total dorsal force delivery to the molars.

From equation 3: if both α and T

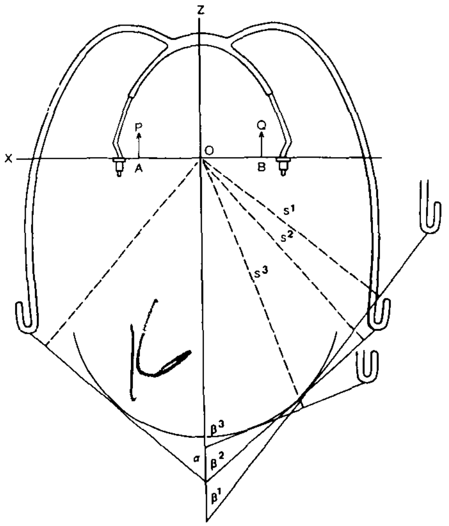

Fig. 16 Increasing angle *ß* will increase s and also the reactive force at Q.

are constant, elongating s will increase the force Q, thus achieving an asymmetrical force delivery.

Since in practice the line of traction must always cut a tangent to the outline of the neck, the distances s and r bear a direct relation to the angles α and β, respectively. In Figure 16 as the angle β increases from β_1 to β_2, to β_3, so the distance s increases from s_1 to s_2, to s_3.

$\therefore$ when $\beta > \alpha$, s will be greater than r.

But from above if $s > r$, Q will be greater than P.

$\therefore$ if $\beta > \alpha$, then $Q > P$.

Hence by increasing the angulation of the line of traction to the midline axis on one side, greater force will be exerted on the molar on the same side. In some clinical situations it is desirable to achieve an asymmetrical force delivery, since one molar may be more mesially placed than the other. The mathematical principles described above may then be considered when designing the appliance.

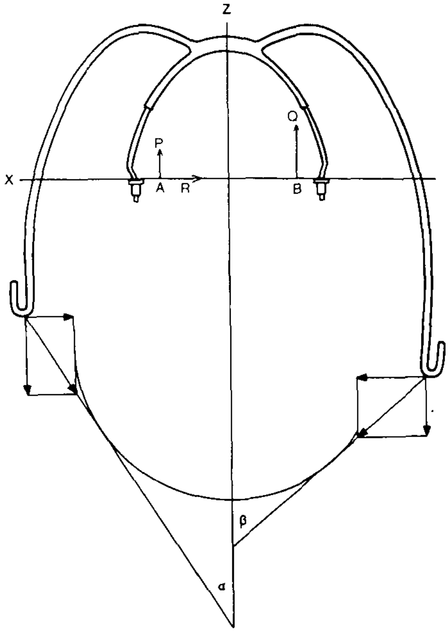

Fig. 17 Lengthening of the outer bow on one side produces a stronger dorsal force on that side.

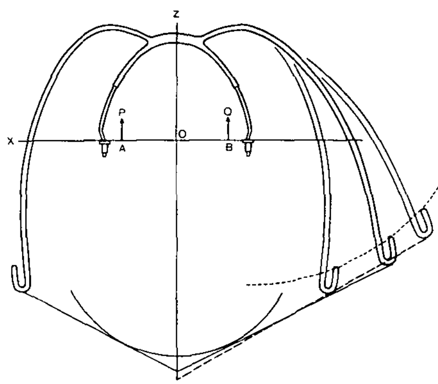

Fig. 18 Bending one arm of the outer bow laterally does not alter the line of traction to any marked degree.

It is necessary to position the outer hooks so that the angulation of the line of traction to the midline axis is larger on the side to which the greater force delivery is desired. This may effectively be achieved by alterations in the relative lengths of the arms of the outer bow. Greater force will be delivered on the side having the longer arm.

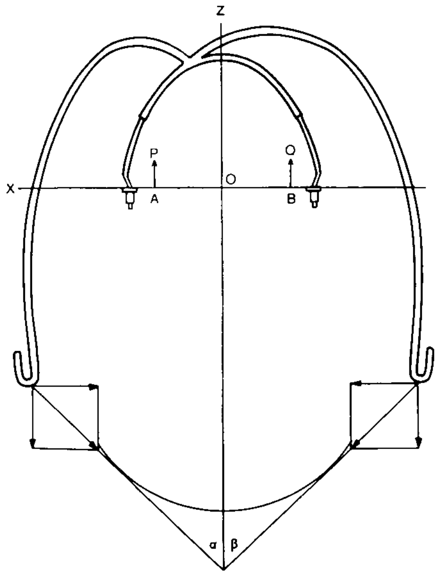

Fig. 19 Offsetting the soldered joint does not affect the force delivery to the teeth.

Observe in Figure 17 how the angulation of the line of traction to the Z-axis is altered. Angle ß is now greater than angle α, and therefore the reactive force Q is larger than the reactive force P. The right side molar is receiving the greater force delivery.

A second modification which can achieve asymmetry is the lateral bending of one outer arm of the facebow. However, this adjustment is capable of effecting only slight changes in the inclination of the line of traction, as is shown in Figure 18. The hook describes a shallow arc as it is moved laterally and little alteration occurs in the inclination of the line of traction.

Clinical Implications

To attain symmetrical force delivery on either side it will be necessary only to ensure that the angulation of the lines of traction to the midline axis are bilaterally equal. In practice, this situation will probably not be exactly obtained but a careful assessment of symmetrical arrangements will achieve an effectively equal force distribution.

The important consideration in the control of the relative forces delivered to each side is the angulation of the lines of traction to the midline axis. Offsetting the soldered joint to one side or the other will not in itself alter these angulations and therefore will not affect the force distribution in the system (Fig. 19).

Although it has been shown mathematically that asymmetrical force delivery can be achieved, it is also true that in practice the desired clinical effect is not readily observed. One possible reason for this disappointing situation is the marked increase in the moments acting about the tooth to which the greater dorsal force delivery is made. The lateral component of force is also increased and the total dorsal force component is correspondingly decreased (Fig. 17).

Conclusions

The functional mechanics of the Kloehn extraoral assembly have been discussed and the relevant clinical deductions and applications may be summarized:

1. It is possible to produce a dorsal force to the upper dentition.
2. If the line of action of the traction force passes through the centre of resistance of the tooth receiving the force, no tipping should occur.
3. However, if this relationship between the line of traction and the centre of resistance is altered, the tooth will tip (Fig. 8).
4. Tipping may be achieved by changing the length of the outer bow and/or changing the angulation between inner and outer bows.
5. If the outer bow is shorter than the inner bow, no adjustment in the Kloehn assembly will bring the line of traction above the centre of resistance. Molar crown tipping

will therefore always occur in a distal direction.

6. In most conventional positions of the inner and outer bows, the desired dorsal force is accompanied by an extrusive component which increases as the line of traction moves upwards (Fig. 12).
7. An intrusive force component can be achieved by bending down a long outer bow but this is seldom clinically practical and will be accompanied by a strong and usually undesirable distal crown tipping (Fig. 13).
8. Mesial crown tipping associated with an intrusive force component cannot be achieved using cervical traction (Fig. 13).
9. Variation in the shape of the inner and/or outer bows is unimportant, provided that no change is brought about in the relationship between the line of traction and the centre of resistance of the tooth to which the force is applied.
10. Eccentric force delivery is possible by lengthening of the outer bow on the side to which the greater force delivery is desired (Fig. 17).
11. An undesirable lateral force component will be produced with eccentric force delivery.
12. Bending one arm laterally without lengthening will not always produce additional force delivery on that side and may even reduce it.
13. Offsetting the soldered joint does not produce asymmetrical forces.

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ACKNOWLEDGMENTS

The authors wish to thank The University of Pretoria for generous financial assistance, Professor A. Bleksley for checking the calculations, Mrs. J. Evans for the drawings, Mrs. L. M. Jansen of the School of Dentistry, Johannesburg, who did the photographs and Mesdames A. Kruger and J. de Bruyn who typed the manuscript. One of the authors, J.F.P.D., wishes to thank the Niels Stensen Stichting of The Netherlands for financial assistance.

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