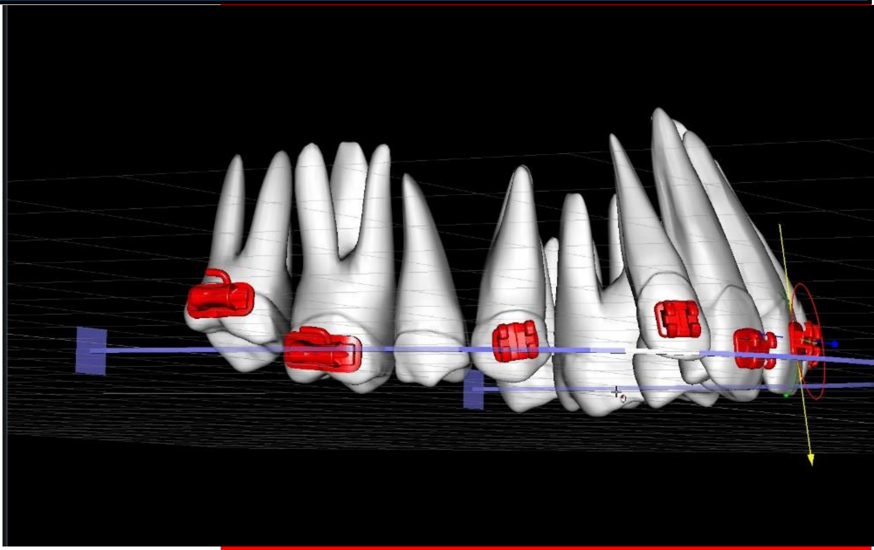
Physics in Orthodontics



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Basic Mechanics Applied to Orthodontics

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1 CONTENTS

2 INTRODUCTION

Orthodontics is built upon basic principles of physics, concerning moving bodies in space. Of course, the movements in orthodontics are made more complicated, as these moving bodies are in the mouth and are subject to more complex force systems than simple mechanics can predict. Biomechanics is an important part of orthodontics and is the study of static equilibrium, and the effects of forces on biological systems. This text will attempt to simplify the biomechanics of orthodontics and provide a framework for clinical applications.

3 BASIC MECHANICS

There are a few basic physics concepts that warrant review prior to delving into biomechanics in orthodontics and its applications in clinical cases.
In orthodontics, we use the three laws of Newton to explain the effects of forces on an object.

3.1 NEWTON'S THREE LAWS

Newton's Laws describe the motion of an object when subject to forces. Newton's Second and Third Laws are the most important in orthodontics.

3.1.1 First Law

In the absence of friction, a body stays at rest or continues in uniform motion in a straight line unless changed by forces acting on it. Newton's first law essentially describes the concept of inertia, or a body's reaction (or resistance) to movement when acted upon by a force. (Fig 1).

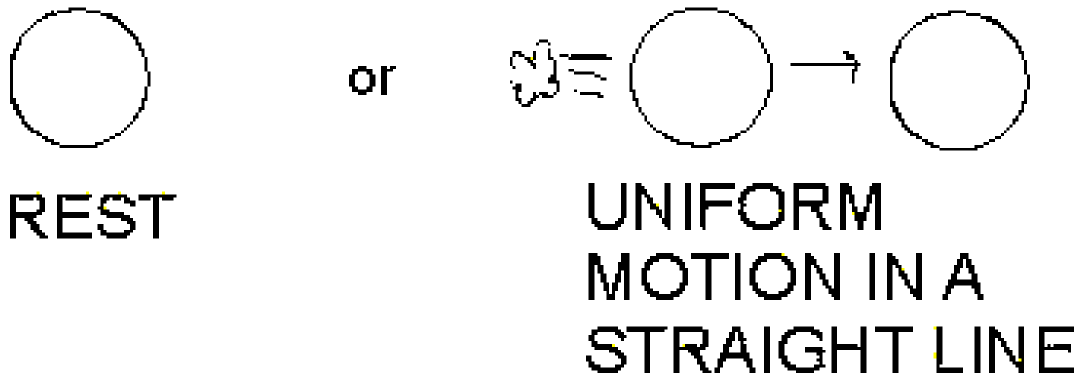


Figure 1: Newton's first law

3.2 SECOND LAW

The acceleration of a body is in the same direction as the force that produces it, and depends on the magnitude of the force and the mass of the object.

$F_{net} = m\ a$

(Force = mass x acceleration)

3.3 THIRD LAW

Newton's third law states that with every action or force, there is an equal reaction force (in the opposite direction). According to this law, whenever two objects interact, they exert action and reaction forces on each other. With any interaction, there is a pair of forces. The forces in this pair (action and reaction) are vectors in that they have a size and a direction. The size of the force on the first object is equal to the size of the force on the second object, and the direction of the force on the first object is in a direction opposite to the direction of the force on the second object.

Consider the interaction between the wheels of an automobile and the road. As the wheels turn, they exert a force on the road. In turn, the road exerts a force on the wheels that is equal in magnitude, and opposite in direction to the force the road receives from the wheels. In a sense, the wheels push the road backwards, and the road pushes the wheels forward (equal and opposite), allowing the automobile to move forwards.

In the mouth, we can see examples of action – reaction systems in a canine retraction setup. The spring pulls the canine back with a magnitude of force. Since the appliance uses the molars as anchorage, there is an equal magnitude and opposite direction force pulling the molars forward (Fig 2). This could be an undesirable side effect. When treatment planning, the undesirable side effects must be accounted for and eliminated or at least minimized.

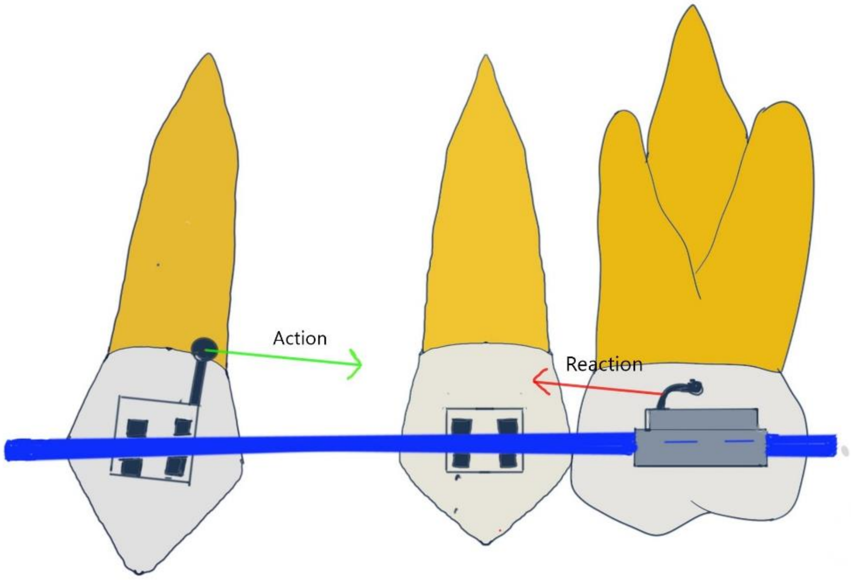


Figure 2: Action and reaction forces place the system in equilibrium. This is a simplified drawing.

4 CONCEPT OF A FORCE

4.1 SIMPLE FORCE:

4.1.1 Definition:

A force is any action that results in the change in the motion of an object. Forces are measured in ounces, grams, or Newtons (approximately 100gr per 1 Newton on planet Earth as the acceleration due to gravity is considered constant and equal to $9.807/s^2$). In orthodontics, the unit of forces is usually the gram(2).

Direction and magnitude of a force

As a force is a vector, the direction of the force is represented . by ? an arrow pointing in the same direction as the movement of the tooth.

The magnitude is represented by the length of the arrow by convention (fig 3).

Figure 3: Simple force with direction and magnitude

4.1.2 Point of application.

The point of application of the force is the location where the force is applied to the object and is by convention the origin of the arrow. The location of the point of application of force is related to the centre of mass as this precise location will determine the tendency of the object to translate or rotate when submitted to this force.

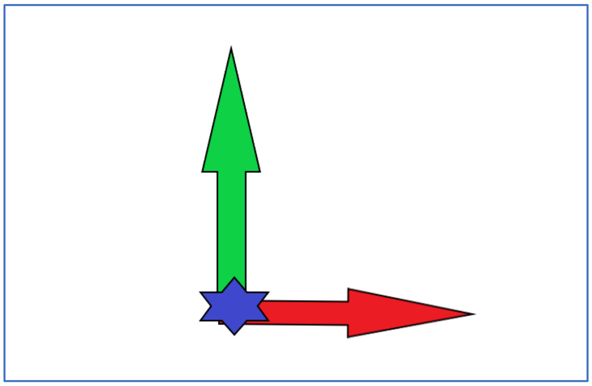


Figure 4: Point of application of forces

In figure 4, the green and red forces are in different directions but have the same point of application.

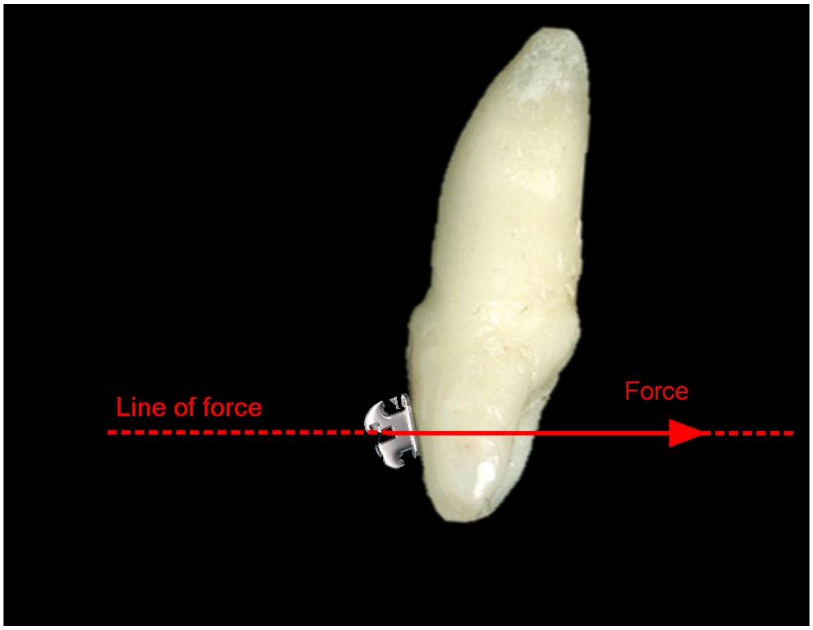


Figure 5: A simple force applied to the bracket of a central incisor. The line of action illustrates the direction of the vector of force.

4.1.3 **Line of action with direction and magnitude.**

The line of action is the geometric representation of the way the force is applied(Wikipedia) . The line of action is the axis of displacement when the force is applied. The direction the force is marked by the arrow . The magnitude is the length of the arrow by convention.

Two forces of equal amplitude acting in the same direction and placed on the same line of action will have the same effect on a rigid body. In figure 6, F1 and F2 will have the same effect on the blue body below. It does not matter if one force is pushing and the other one is pulling. The net effect will be identical.

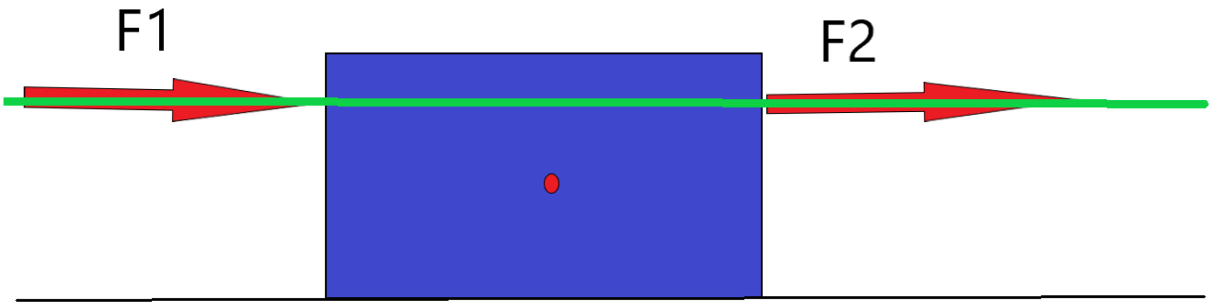


Figure 6: Line of action of forces

4.1.4 **Law of Transmissibility of Force**:

The effect of a force on a body is the same when applied anywhere along its line of action (Fig 7). For example, if the line of action is the long axis of the tooth, it does not matter whether the force is applied at the incisal edge, the bracket, or the cingulum, as long as the force is in the same direction and magnitude, the effect remains the same.

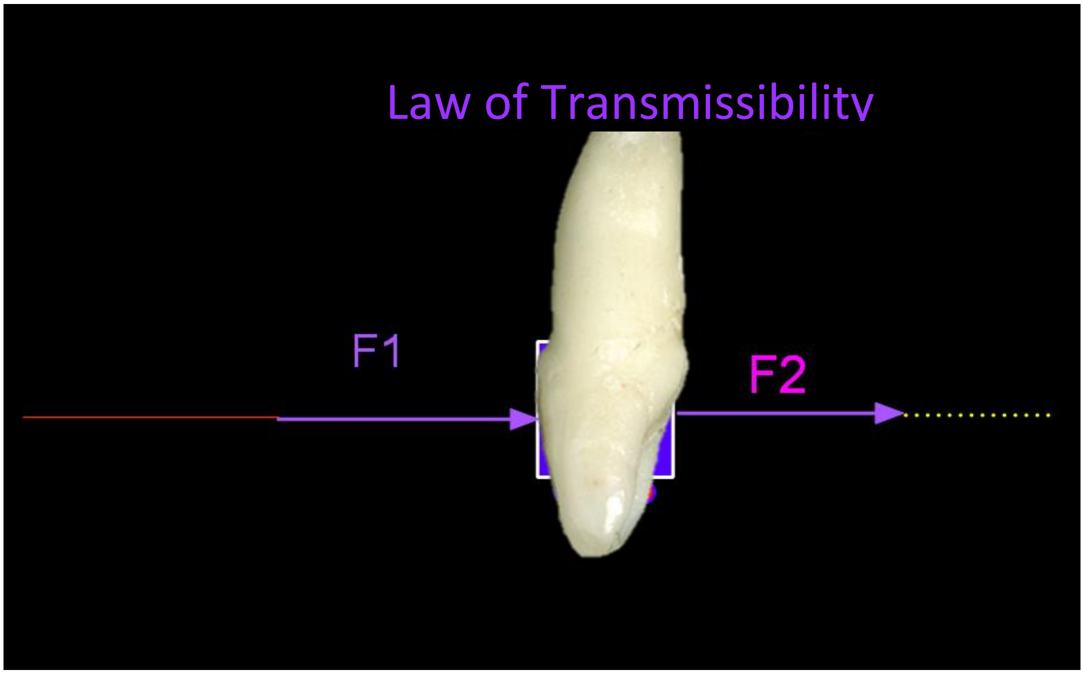


Figure 7: Law of transmissibility of force: F1 and F2 will have the same effect

4.1.5 **Point of application of force:**

The law of transmissibility tells us that forces of same magnitude and direction have the same effect no matter where the point of application is located along the same line of force.

Scalars are used to describe forces; scalars have a magnitude, but no direction. Vectors have magnitude and direction (vectors are used in the free body diagram).

Rigid Bodies: These do not change shape under the influence of forces (such as compression and tensile forces). Teeth are rigid bodies; the same cannot be said for soft tissues!

4.1.6 **Centre of Mass**

The centre of mass represents the balance point of a system. In simple objects such as a tooth, the centre of mass is a point where the position of distributed mass is equal to zero. If no force(s) act on a body of mass, it would act as if all its mass was concentrated at that single point (the centre of mass).

1. Centre of Mass: balance point of a system

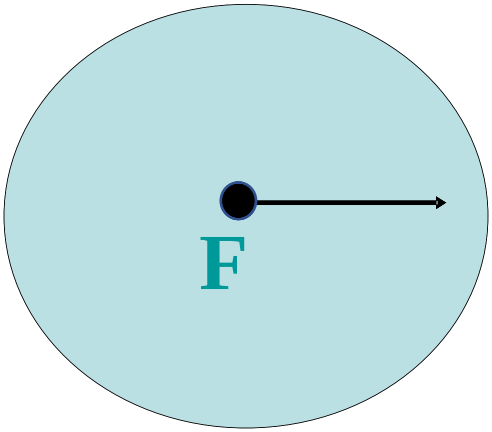


Figure 8 : Centre of Mass

If a force goes through the Centre of Mass, the object will move in the direction of the force without any rotation (pure translation).

This would be the same as a box, or any other object for that matter, on the moon (or in an environment where there are no forces acting on the tooth) (Fig 9). This is obviously not a realistic situation, but more of a theoretical concept!

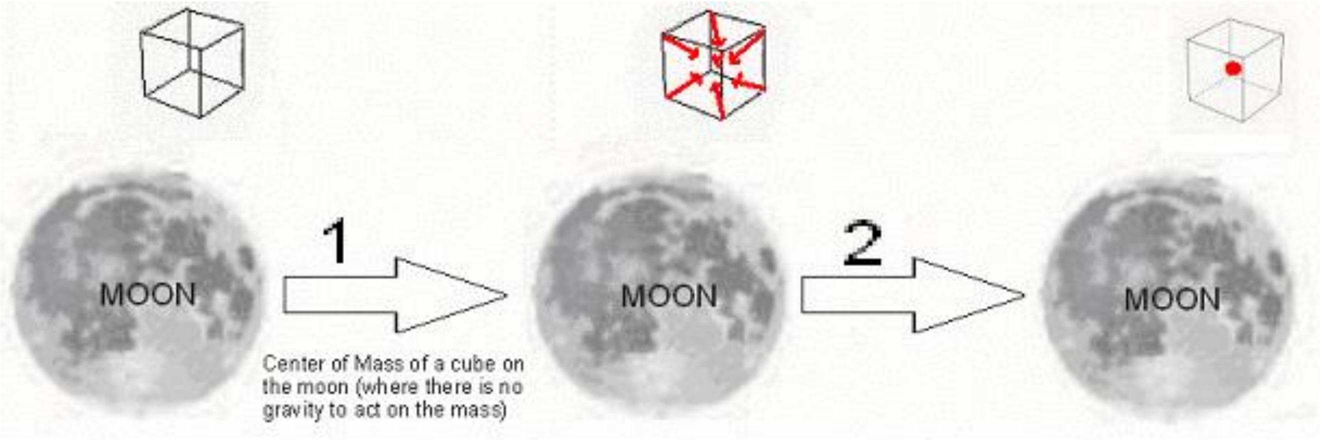


Figure 9: Centre of Mass on the moon

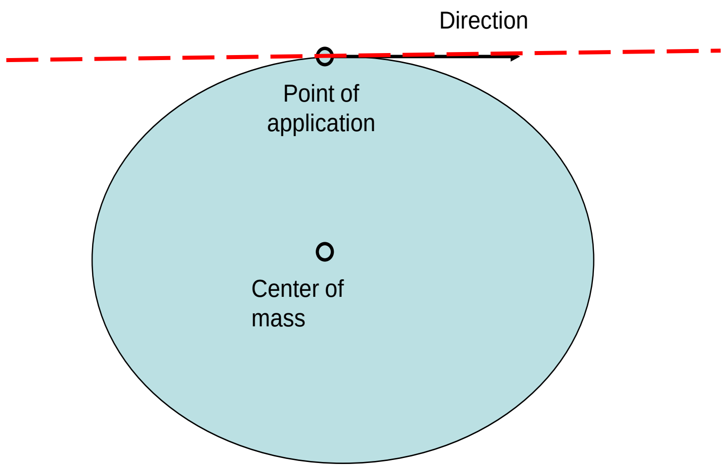


Figure 10: Line of action of a force placed at a distance from the centre of mass

If the line of action of a free body is placed away from the centre of resistance, a combination of rotation and translation is to be expected (figure 10).

5 CENTRE OF RESISTANCE (CR):

The centre of resistance is an important concept in orthodontics as the teeth are not free bodies, the roots being secured to the alveolar bone by the periodontal ligament. The centre of mass and the centre of resistance are not located in the same position. CR is located more apically than the centre of mass. It is a mathematical point at which all resistance to displacement may be thought to be concentrated. Calculations of force systems in relation to their ability to translate or rotate are done in relation to the centre of resistance.

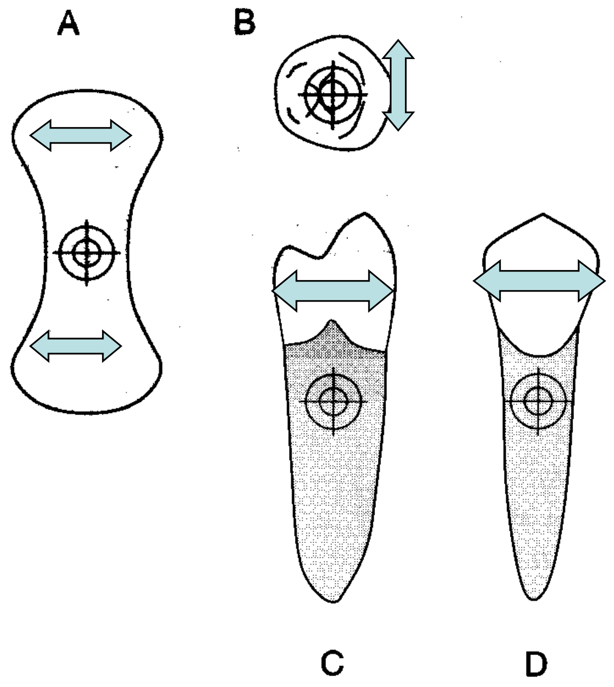


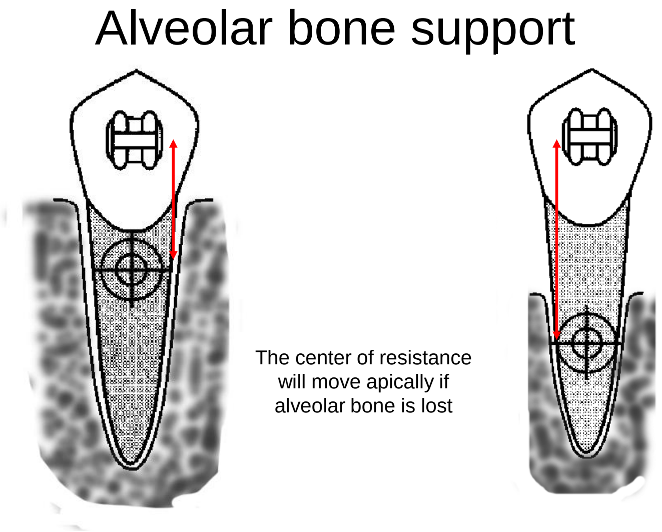
Figure 11: Localization of the centre of resistance according to several views:
A. Radicular, B: Occlusal. C: Labio-lingual, D.: Mesio-Distal

The centre of resistance varies with each tooth and according to the periodontal support present. It is located approximately halfway at the root level . (Fig 11)

The centre of resistance considers all the forces acting on a body. For a tooth, it includes forces from the periodontal ligament (PDL), blood vessels, bone, and connective tissue (Fig 12). The centre of resistance can be considered for a single tooth, or for a group of teeth, if they have been anchored together (they therefore act together as one larger mass).

<u>Importance of the centre of resistance</u>: When forces are applied on teeth, it is imperative to assess their three-dimensional effects and the resulting movements that will occur once the tooth is subjected to this force system.

5.1 VARIABILITY OF THE CENTRE OF RESISTANCE IN RELATION TO PERIODONTAL SUPPORT


Alveolar bone support

The center of resistance will move apically if alveolar bone is lost

Figure 12: The centre of resistance moves apically when horizontal bone loss occurs.

When a patient presents with reduced periodontal support, the crest of the alveolar bone is more apical. The centre of resistance of the tooth has moved dramatically more apically, and the distance from the bracket to the centre of resistance increases almost by two-fold (figure 12). If the same force is applied to the bracket on these two teeth, a different orthodontic movement will result. The tooth on the right will tend to rotate more according to the increased distance of the line of force at the centre of resistance of the tooth.

5.1.1 Centre of resistance for a single tooth:

The centre of mass is always placed more occlusally than the centre of resistance due to the “resistance “of the periodontal ligament and dentoalveolar bone. As this resistance is impossible to quantify for each tooth and for each patient, the centre of resistance is a theoretical concept but can be used as an average to create optimized force systems.

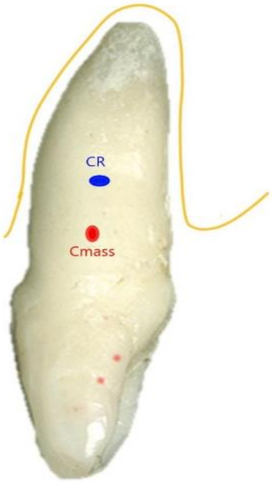


Figure 13: Centre of resistance (CR) vs Centre of Mass (Cmass) of a monoradicular tooth

In cases where the periodontal support is constant, the centre of resistance of different teeth will be at different levels. The upper canines will have a higher centre of resistance while the premolars and lateral incisors will be lower.

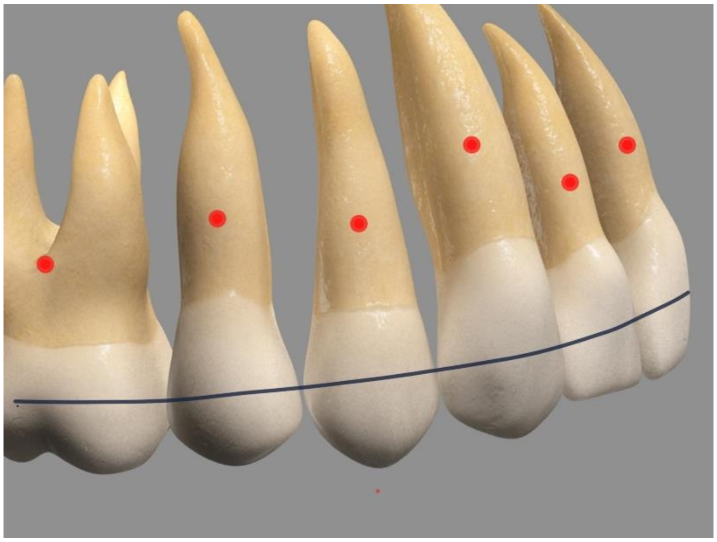


Figure 14: Different centre of resistance positions (if we consider the periodontal support even and normal)

It is evident, therefore, that the centre of resistance is different between different teeth with different root length and anatomy, for example, between incisors and molars, or premolars and canines. Its position also varies with alveolar bone height, so that it would be different in a child versus an adult with periodontal disease (the centre of resistance moves more apically in adults with bone loss) (Fig 14).

Another way to think about the centre of resistance is that it is the point on the body where a single force (at this point) results in pure translation (Fig 15).

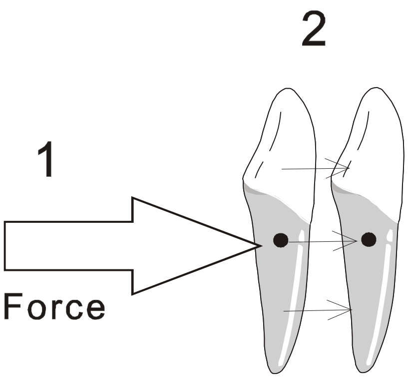


Figure 15: Forces acting at the centre of resistance result in pure translation

5.1.2 **Centre of resistance for a group of teeth**.

When teeth are tied by brackets and wires, a new centre of resistance is created, and the group of teeth is now considered as a single object.

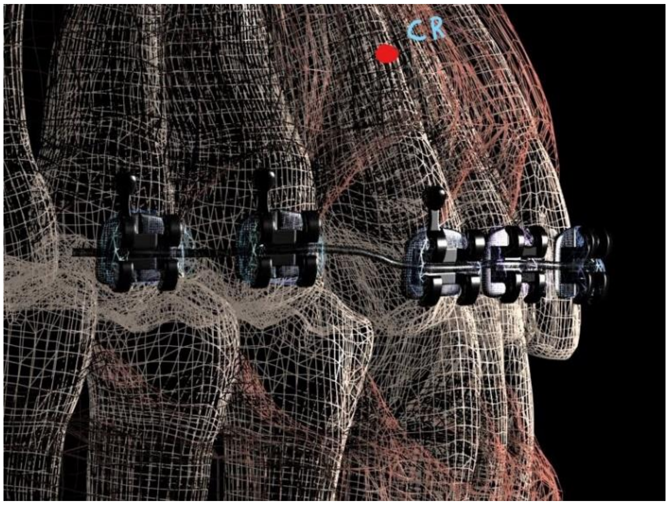


Figure 16: Centre of resistance for a group of teeth

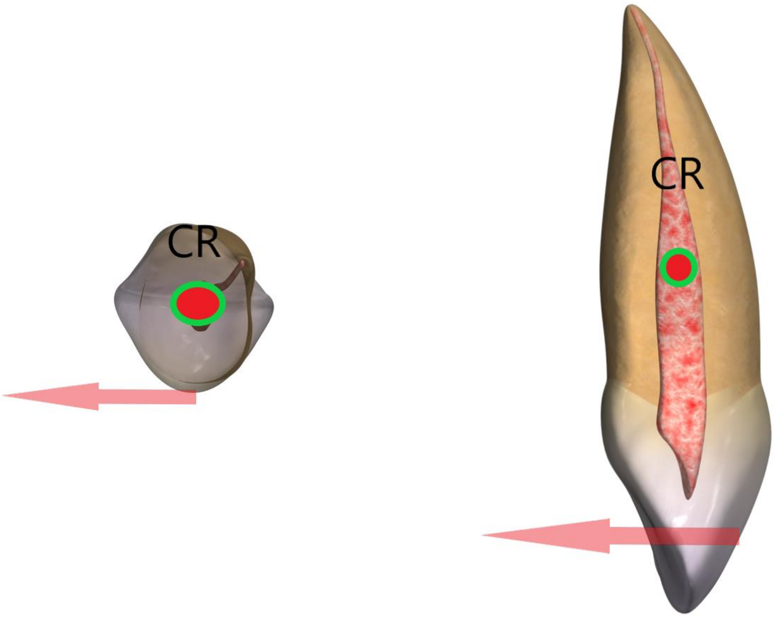


Figure 17: When a force is applied to the bracket, the line of force is always at a distance from the centre of resistance

5.1.3 **Combination of forces. Resultant of force or net force**

In orthodontics, combination of forces in the three planes of space is frequently used and it is useful to calculate the net force (or resultant force). The parallelogram rule is used to calculate the sum of the vectors.

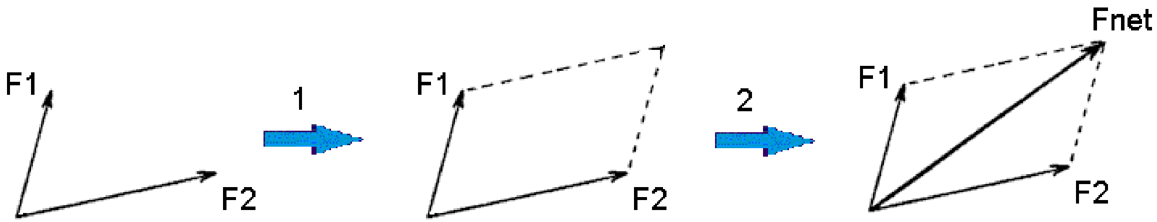


Figure 18. Parallelogram Rule

It is important to remember that the force (Fnet) is the net force, which is the vector sum of all forces (F1 and F2). The parallelogram rule allows us to find the net force: Forces F1 and F2 are vectors and have magnitude and direction. When F1 and F2 are at an angle to each other, a parallelogram is created by drawing F1 and F2 adjacent sides. The diagonal running through the parallelogram is the resultant force F_{net} (Fig 18).

Calculations of the sum of 2 vectors (Please refer to this URL for detailed explanations: https://www.mathstopia.net/vectors/parallelogram-law-vector-addition)

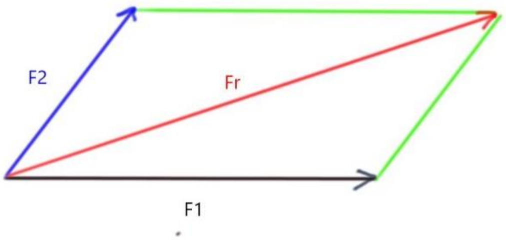


Figure 19: Calculation of the sum of two vectors.

In order to calculate the magnitude of the resultant force Fr, we use the fomula Fr = F1 + F2. We need to extend the line of action of F1 to create a square triangle OXR and add the α and β angles.

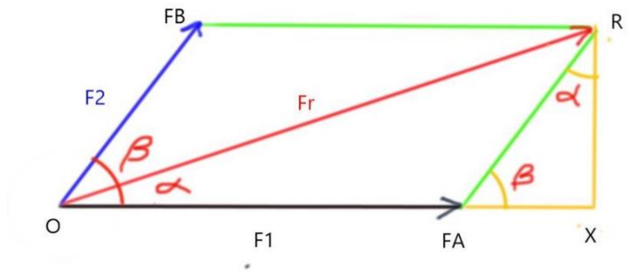


Figure 20: Extension of the parallelogram.

<u>Calculation of the amplitude of Fr:</u>

$Fr^2 = OX^2 + RX^2$

OX = OFA + FAX or

$Fr^2 = (OFa + FaX)^2 + Rx^2$

Once fully expanded, we get

We know that Cos β = adjacent side to β angle/hypotenuse

FaX/F2 or FaX= F2Cosβ and sin β = Rx/F2 or RX= F2sinβ

$Fr^2 = F2\sin\beta +$

After substitution of values: $Fr = \sqrt{F1^2 + 2F1F2\cos\beta + F2^2}$

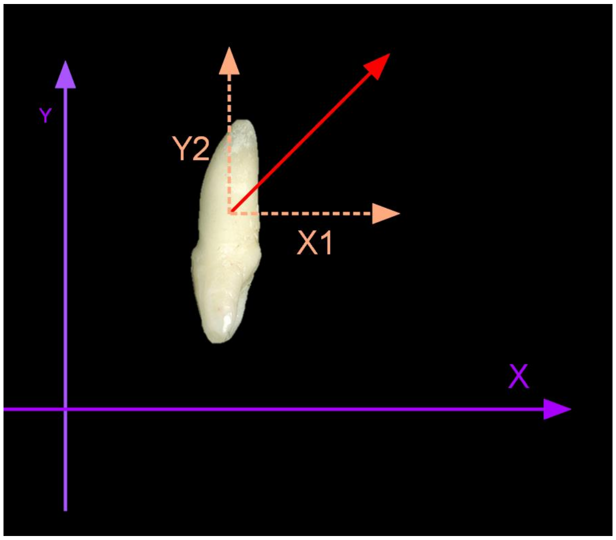


Figure 21: Resultant (net) force when forces at 90 degrees

In the case where we place the forces at 90 degrees, the equation is simplified and becomes

$Fr = \sqrt{X1^2 + FY2^2}$

6 CENTRE OF ROTATION:

The Centre of Rotation is the point about which the object rotates. This varies with the location of the centre of resistance and the force applied to the object. Pure rotation occurs when the centre of rotation is at the centre of resistance. Pure translation occurs when the centre of rotation is at an infinite distance away from the centre of resistance.

To locate the centre of rotation about which a rotational tooth movement occurs (Fig 22), choose any two points on the tooth (or object), and draw a line between the before and after positions of each point. The point of intersection between the perpendicular lines is the centre of rotation.

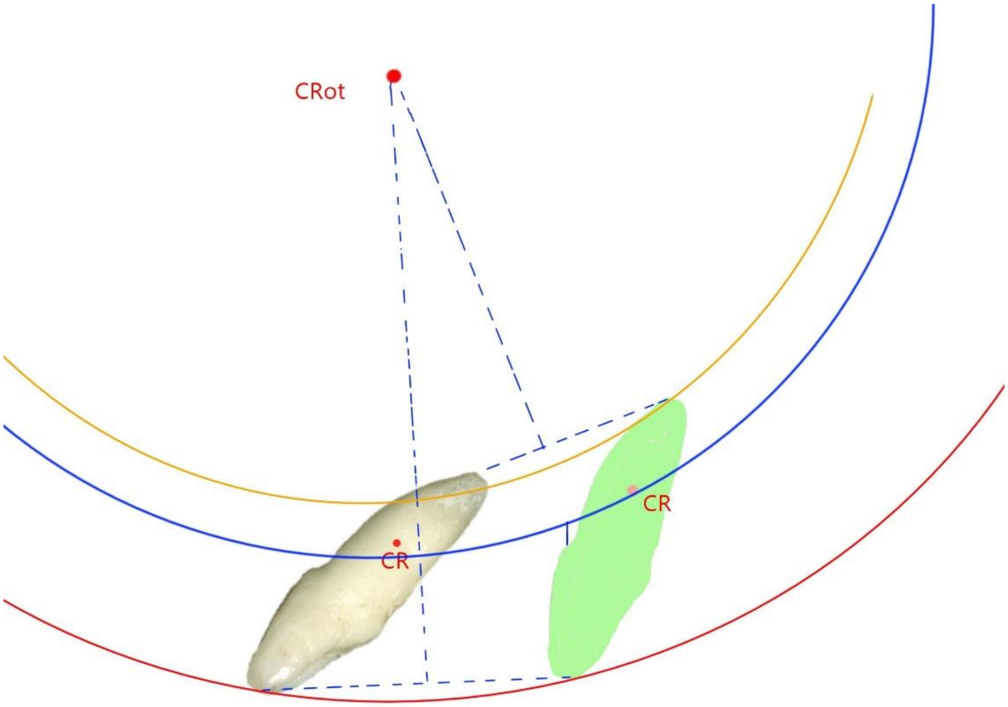


Figure 22: Method to locate the centre of rotation

6.1.1 **Free Body Diagrams**

Free body diagrams help to predict the effect of different forces acting on a body at the same time (net force) or to resolve a force into its component parts.

An example of a free body diagram, with F1, F2, and Fnet (recall the parallelogram rule) (Fig 23).

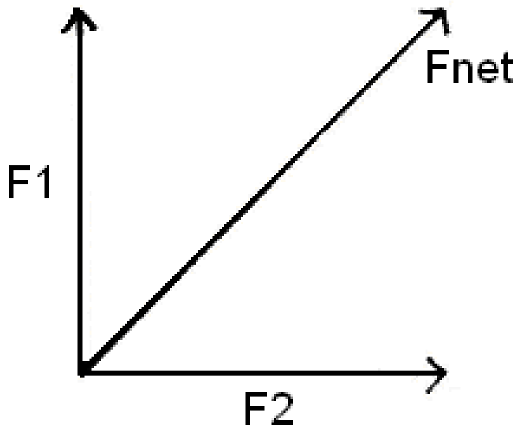


Figure 23: Free body diagram

A clinical example of the use of a free body diagram is with an intrusion arch and elastics

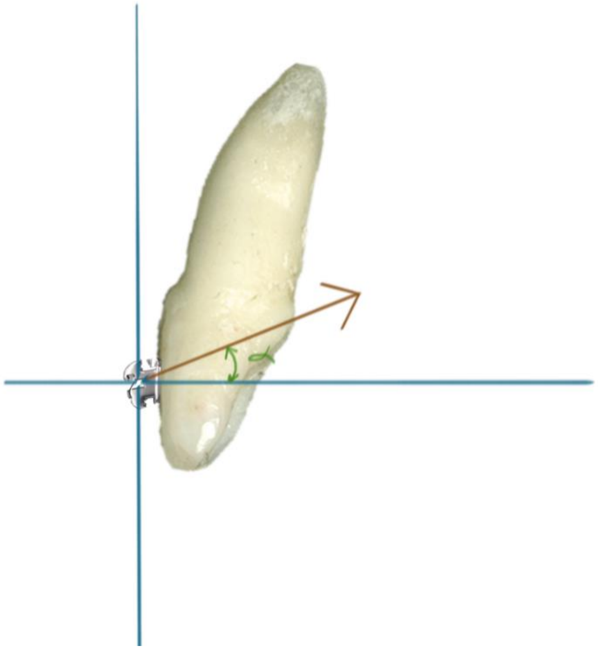


Figure 24: Simple force to intrude and retract upper incisor

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A force F is applied. It has intrusive and retrusive component parts. If we know the magnitude of the applied force and its angulation, we can find out the magnitude of the intrusive and retrusive forces using simple trigonometry (Fig 24-25)

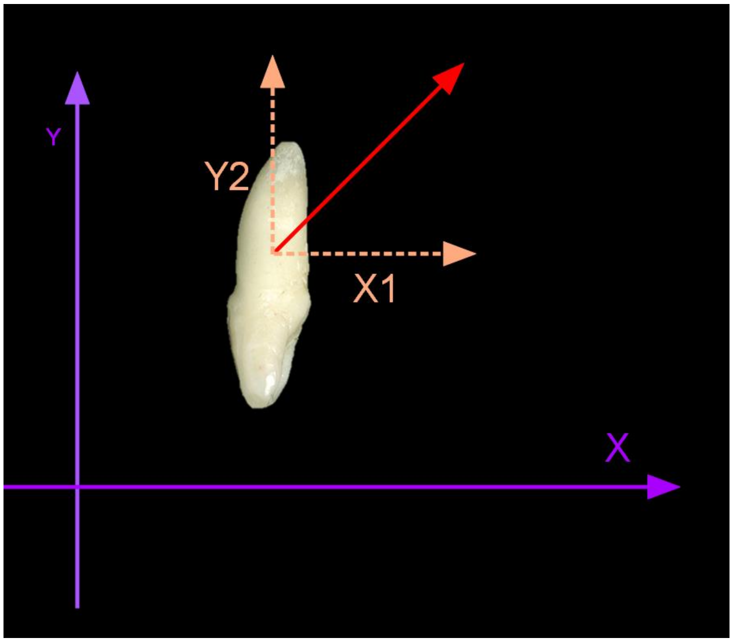
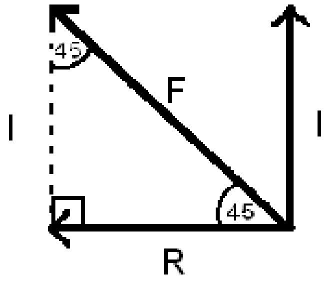


Figure 25: Free body diagram and the forces applied from a headgear

If we know that Fnet = 500g, we can solve for I (Intrusive force) and R (Retrusive force) using the right triangle rule (Fig 26).



$$\sin 45 = \frac{I}{F}$$

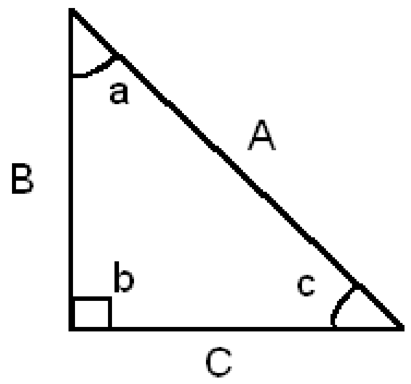
$$\begin{aligned} I &= F \sin 45 \\ &= 500 \sin 45 \\ &= 353 \text{ g} \end{aligned}$$

$$\cos 45 = \frac{R}{F}$$

$$\begin{aligned} R &= F \cos 45 \\ &= 500 \cos 45 \\ &= 353 \text{ g} \end{aligned}$$

Figure 26: Finding the resultant intrusive and retrusive forces using the right triangle rule

Thus, a 500g force in the direction of Fnet is the same as a 353g force in the direction of I, and 353g in the direction of R placed on an object at the same time.



$$\sin a = \frac{\text{opposite}}{\text{hypoteneuse}} = \frac{B}{A}$$

$$\cos a = \frac{\text{adjacent}}{\text{hypoteneuse}} = \frac{C}{A}$$

$$\tan a = \frac{\text{opposite}}{\text{adjacent}} = \frac{B}{C}$$

Figure 21: Trigonometric calculations

7 TOOTH MOVEMENTS

Teeth move in three dimensions of space. It is important to be aware of the different types of movement possible when planning a treatment to account for desirable and undesirable tooth movements.

7.1 TRANSLATION

During translation, all points on the body move in the same direction and with the same magnitude (Fig 28). The centre of rotation is effectively at an infinite distance away from the tooth because there is no rotation.

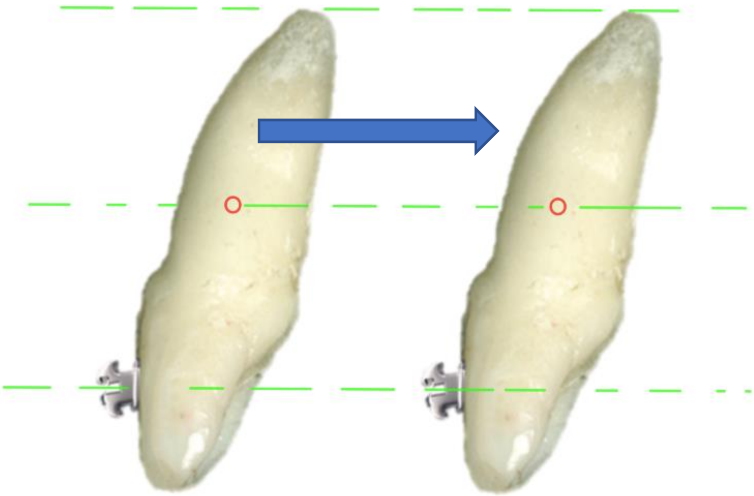


Figure 28: Translation of the central incisor

7.2 ROTATION (PURE)

Pure rotation occurs when a body rotates about the centre of resistance (Cres) (i.e. when the centre of rotation is at the centre of resistance (Fig 29).

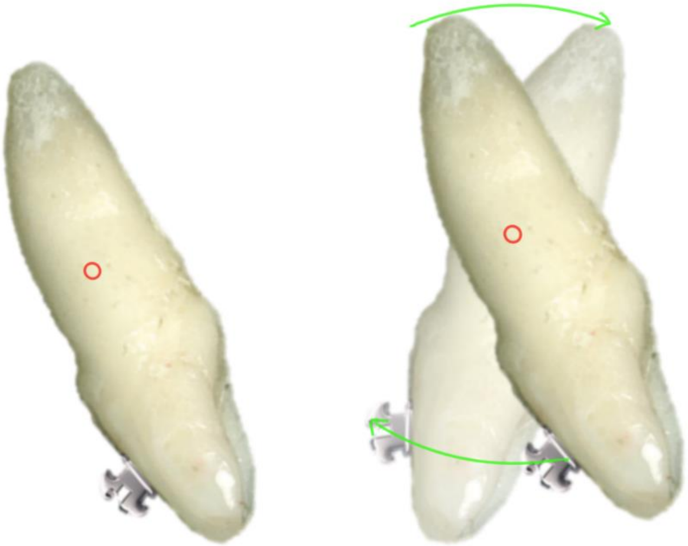


Figure 29: Pure Rotation

7.3 TIPPING

With tipping, the result depends on where the force is applied.

7.3.1 Uncontrolled Tipping: When a force is placed on the crown, the crown moves in one direction, while the root moves in the other. In this case, the centre of rotation is near, or apical to the centre of resistance, so the tooth tips about Cres (Fig 30).

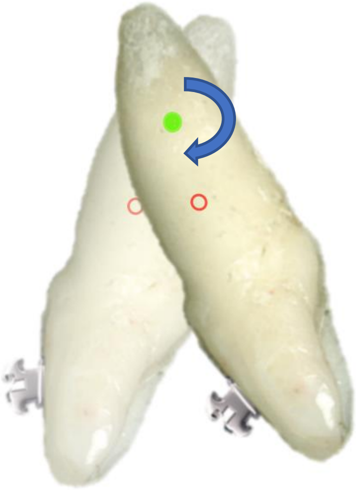


Figure 30: Uncontrolled tipping

7.3.2 Controlled Tipping:

The centre of rotation is at the apex of the tooth. This involves a moment and a force, and the tooth tips about the Crot (Fig 31).

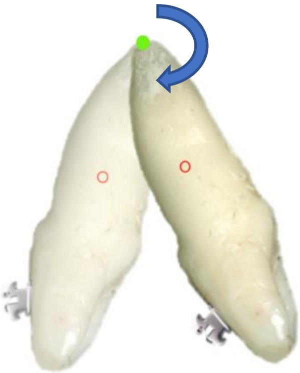


Figure31: Controlled tipping

A) For example, in the correction of a Class II Division I malocclusion with maxillary anterior proclination, the use of uncontrolled tipping could result in perforation of the buccal bony plate, whereas controlled tipping will result in the movement of only the crown, so the root will not perforate the buccal bony plate.

7.3.3 Root movement

Root movement occurs when the centre of rotation is at or near the incisal edge, and the rotation occurs about this point (Fig 32). The crown therefore is displaced less than the root. Root movements take more time because of the bone resorption required for the movement to occur.

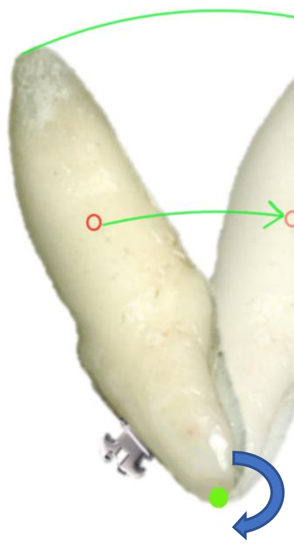


Figure 32: Root movement

7.3.4 Intrusion/Extrusion

Intrusion and extrusion involve movement along the long axis of the tooth (Fig 33, Fig 34). Recall from translation (fig. 28), the centre of rotation is at infinity in this type of movement (because there is no rotation) In other words, the tooth is rotating about a point that is at an infinite distance away such that we do not see any rotation, just a translation or intrusion/extrusion movement.

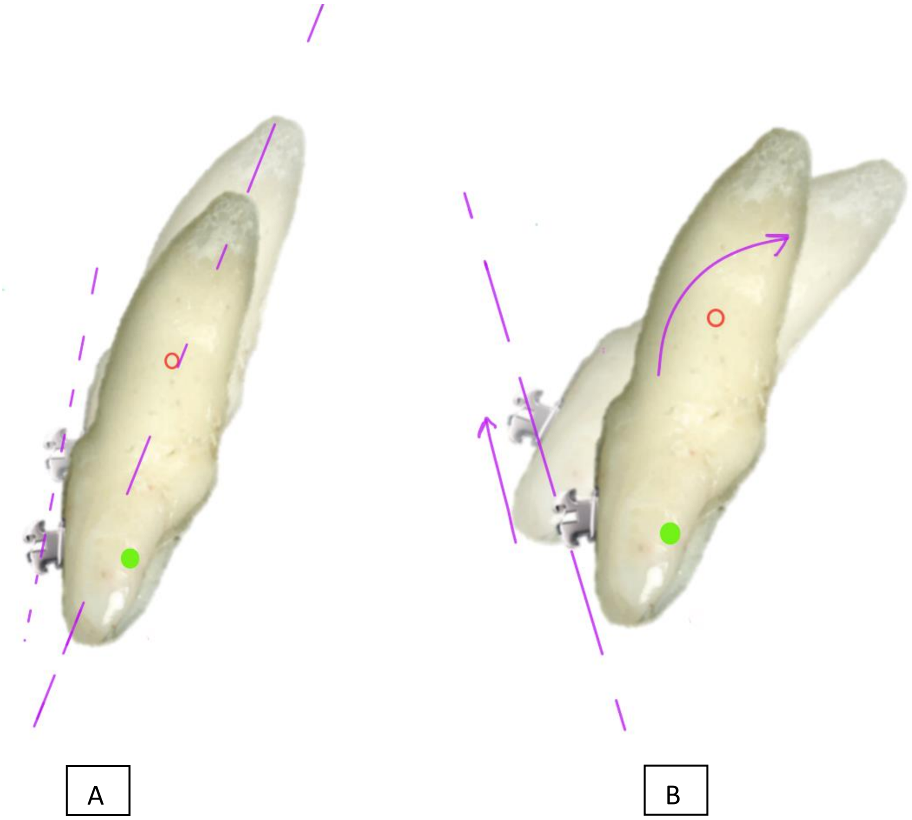


Figure 2: A. Intrusion of an extruded incisor. B. Relative intrusion

Intrusion: In fig 33A, (in the following example, undesirable effects of intrusion are not considered: while one tooth is intruded, adjacent teeth are extruded unless anchored. Refer to discussion on anchorage). Relative intrusion is the result of proclination and intrusion (fig 33B)

Extrusion: (in the following example (Fig 34), undesirable effects of extrusion are not considered: while one tooth is extruded, adjacent teeth are slightly intruded unless anchored. Refer to discussion on anchorage)

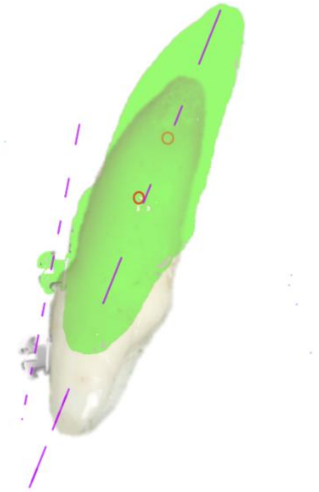


Figure 34:Extrusion of an intruded incisor

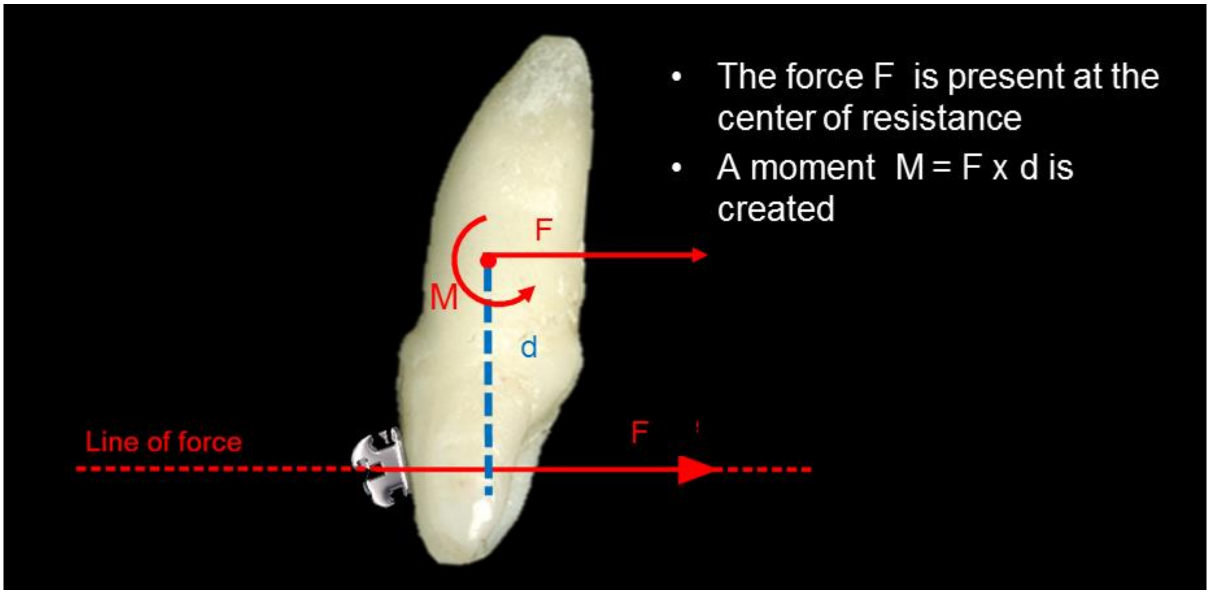
8 FORCE SYSTEMS

To understand how to create desired tooth movements, one should consider force systems. Force systems are made up of a moment and a force, whose ratio determines the type of movement produced. This section will cover moment, force couple, moment to force ratio, and movements when forces and systems are varied.

8.1 MOMENT

Moment is the tendency of the force on a body to cause rotation. To calculate the moment of a force, multiply the magnitude of the force, and its perpendicular distance from the centre of resistance about which the moment occurs (Fig 35).

M = F x d



- The force F is present at the center of resistance
- A moment M = F x d is created

Figure 35: Moment produced by a force applied at a distance from the centre of resistance

8.2 FORCE COUPLE

A couple is a pure moment and occurs when two forces (F1, F2 equal and opposite) are separated by a perpendicular distance. To calculate the moment of the force couple, consider the forces separately.

Example: F1 and F2 do not produce translational effects because they are of equal and opposite directions, and therefore cancel each other out. The moments of the forces do not cancel each other out because they produce rotation in the same direction (imagine the rotation about the centre of resistance when forces are applied from F1 and F2). To find the total moment on the system, add the moments; this is a force couple. The force couple is irrespective of where the forces are applied on the body (or tooth). Consider the following example of the force couple (Fig 36)

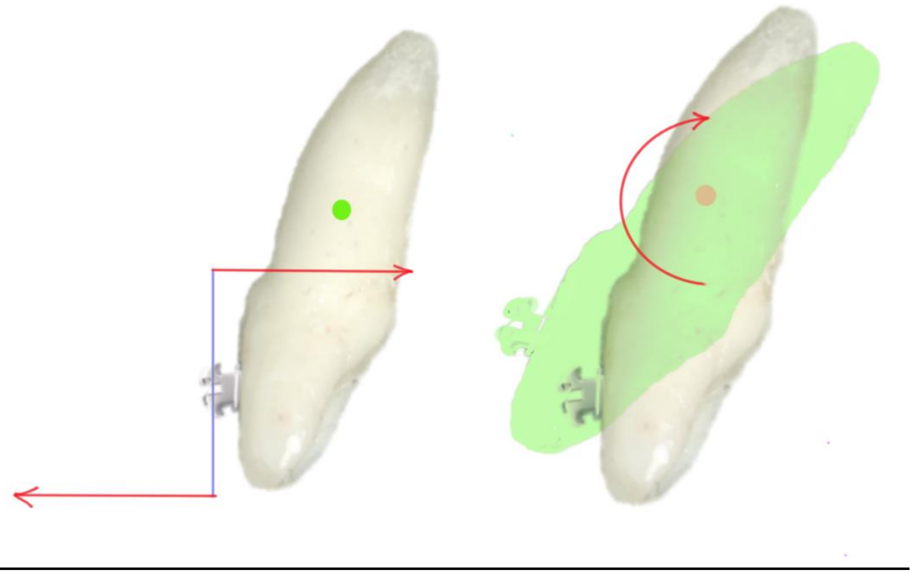


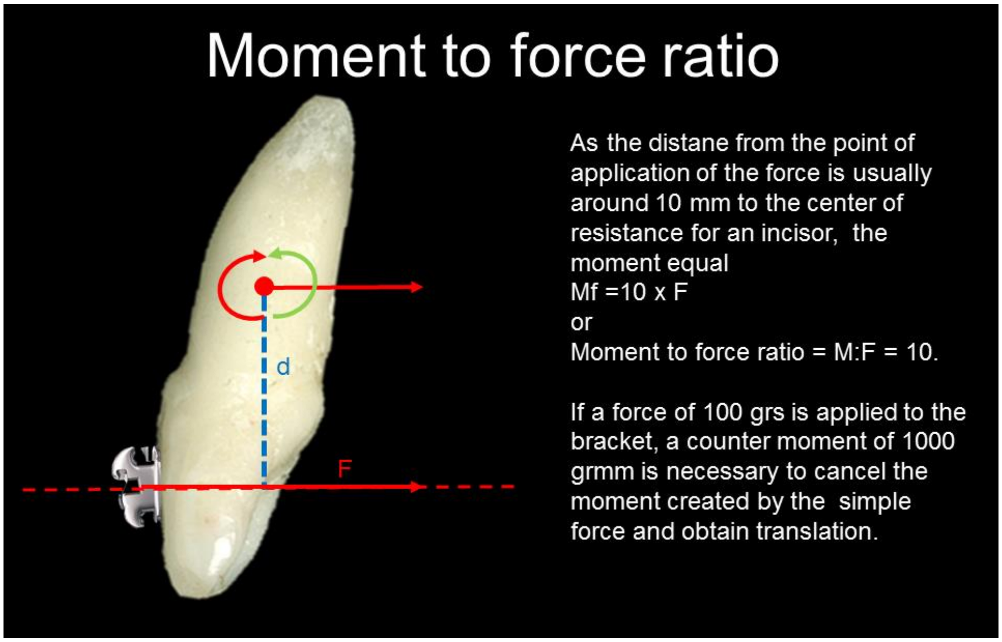
Figure 36: Force couple: example 1

Since the force couple is irrespective of where the forces are acting on the body, the same result as the above example can be attained by placing the forces F1 and F2 in a new location (the new locations in the following example are more biologically and clinically sound).
In conclusion, it does not matter where a couple is acting on a tooth, the net moment on this system will be equal to one force multiplied by the distance between the forces.

8.3 MOMENT TO FORCE RATIO

The moment to force ratio combines the translational and rotational movements. The ration is determined by the amplitude of the force multiplied by the perpendicular distance to the centre of resistance of a tooth or a group of teeth (Fig 37).

The following examples demonstrate controlled tipping of a tooth using combined translation and rotation movements (simple force and moment) (Fig 38, Fig 39).

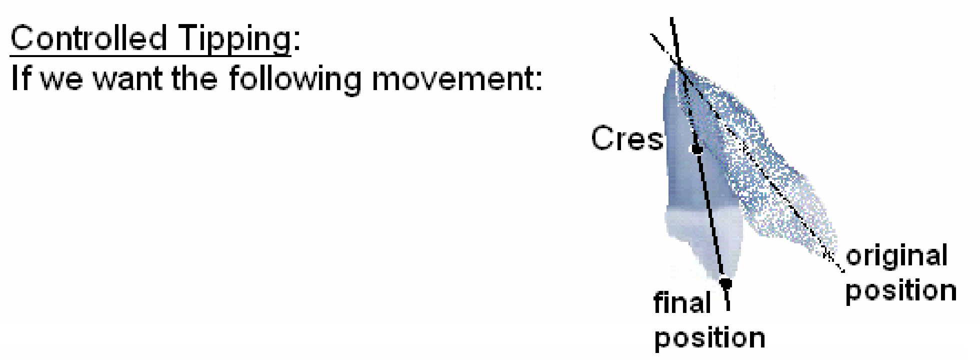


Moment to force ratio

As the distane from the point of application of the force is usually around 10 mm to the center of resistance for an incisor, the moment equal
Mf =10 x F
or
Moment to force ratio = M:F = 10.

If a force of 100 grs is applied to the bracket, a counter moment of 1000 grmm is necessary to cancel the moment created by the simple force and obtain translation.

Figure 37: Moment to force ratio for translation



Controlled Tipping:
If we want the following movement:

Figure 38: Desired movement

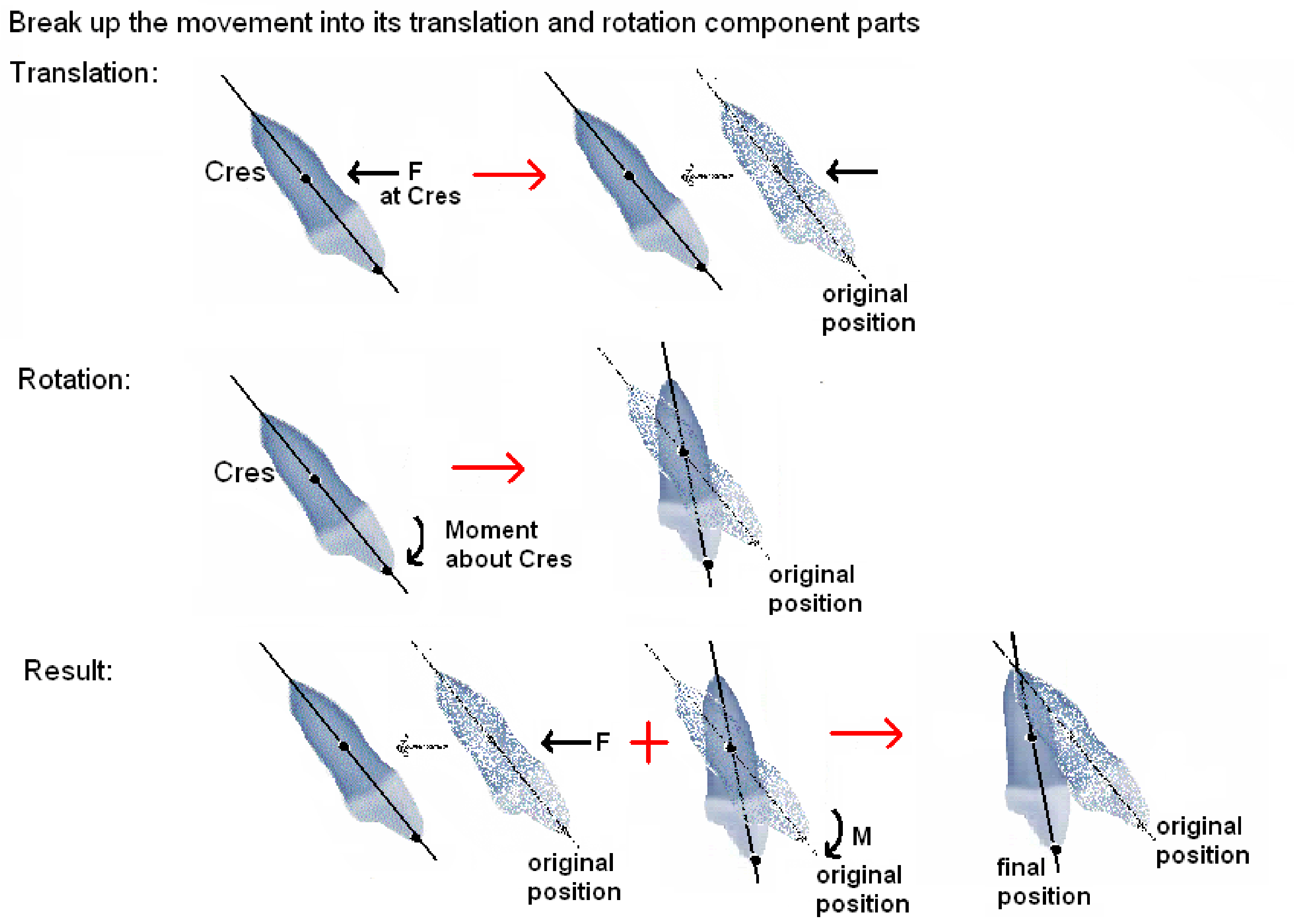


Figure 39: The combination of translation and rotation to achieve controlled tipping

By changing the M/F ratio, different centers of rotation can be produced. Figure 40 demonstrates the effects of changing the M/F ratio on controlled tipping. If the M/F ratio is decreased (M is constant or decreased, and F increases), then you get more translation movement because the centre of rotation goes towards the apex of the tooth (in other words, away from the Centre of Resistance, towards infinity). If the M/F ratio is increased by increasing the M or decreasing the force, there will be more rotation since the centre of rotation will move towards the centre of resistance (in other words it moves more incisal from its previous position).

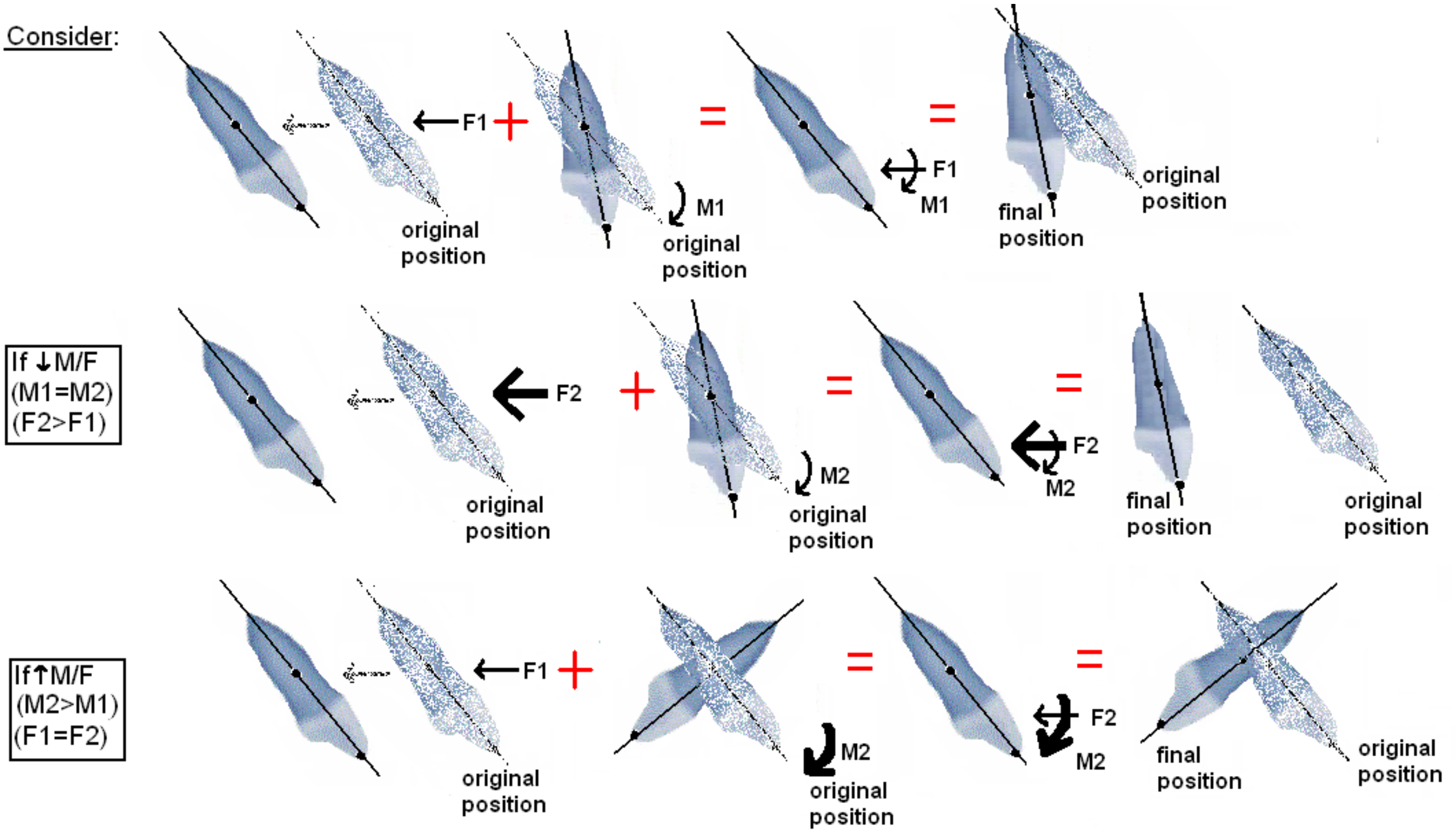


Figure 40: Effects of changing the moment to force ratio (M/F)

8.4 MOVEMENTS WHEN FORCES AND SYSTEMS ARE VARIED

We can apply the knowledge learned from the equivalent force systems section to a real-life example such as incisor retraction. Using a molar as anchorage, we cannot just place a straight wire between the incisor and the molar and use a loop in the wire with an elastic to retract since this situation will result in uncontrolled tipping of both teeth (the Centre of Rotation will be at the Centre of Resistance). (Fig 41)

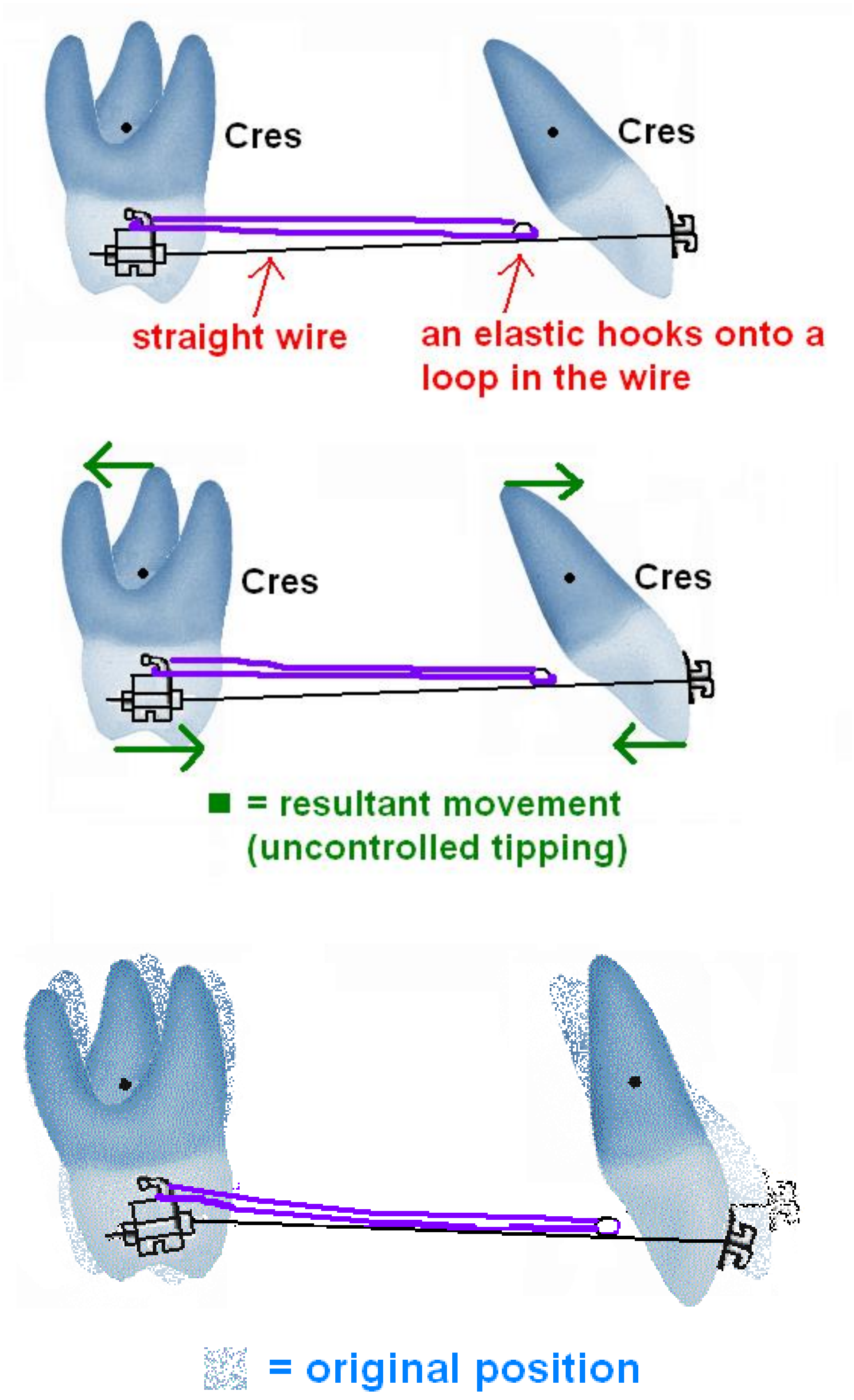


Figure 41: Incisor retraction using elastic on loop in wire: Result is uncontrolled tipping.

To control the movement, we need to add a moment at the crown to counter the moment created by the force, to produce as pure of a translation movement as possible (recall equivalent force systems again). We can create a moment at the crown of the tooth by bending the wire in a location such that there will be a tendency of the tooth to tip (in a controlled way) when the wire is in place. The following example illustrates this concept (Fig 42).

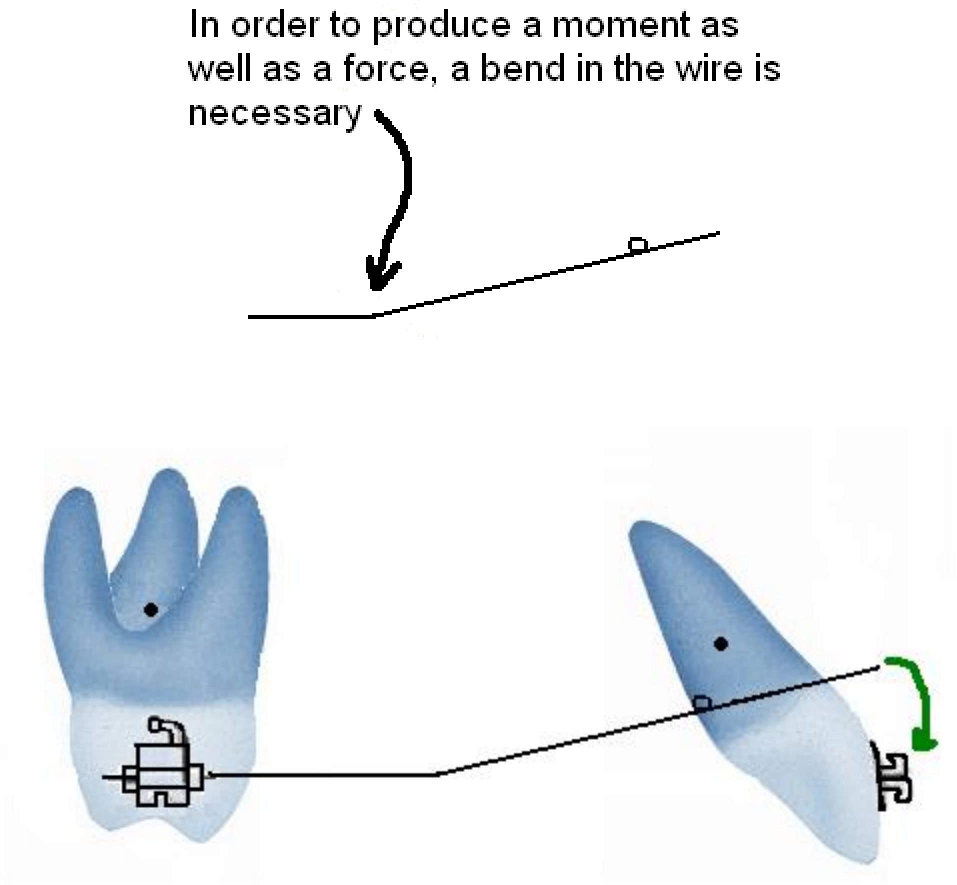


Figure 42: Producing a moment with a bend in the wire, as well as a force with a loop in the wire

For the wire to fit into the slot of the bracket on the incisor, the wire must be lightly forced into place. Once it is in place with the elastic, it exerts the following forces on the two teeth in question (Fm, Mm are the force and moment on the molar; Fi, Mi are the force and moment on the incisor).

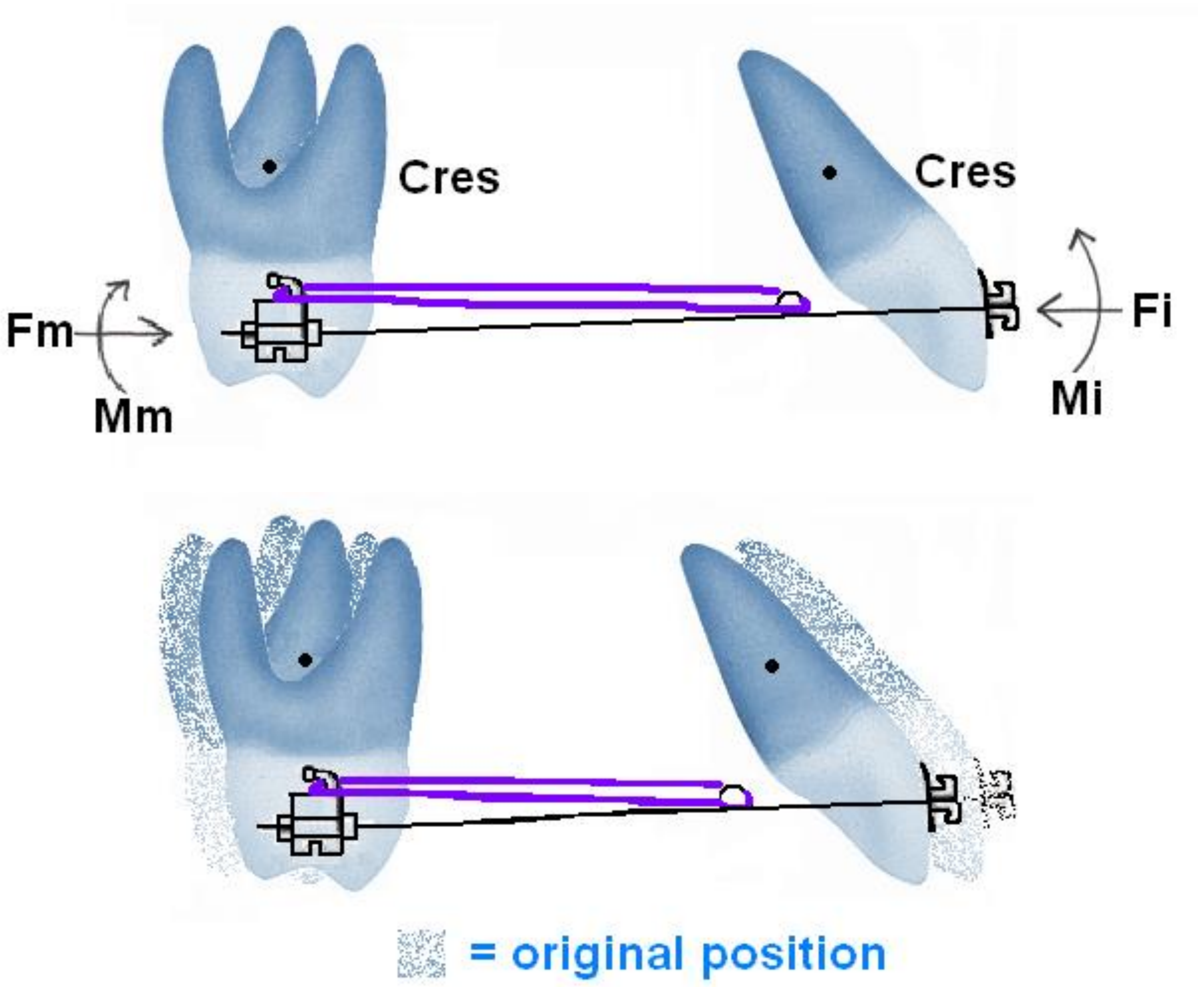


Figure 43: Resulting movement with bend and loop in wire is incisor retraction (tipping is controlled and minimized)

This example demonstrates that by adjusting the M/F ratio, we can produce a desired effect of translation (Fig 43). This M/F ratio can be adjusted depending on the goal in mind (some tipping may be desired). The M/F ratio can be adjusted accordingly, and if there is control of the movements, the goal will be achieved.

The M/F ratio is affected not only by the placement of an elastic and a bend in the wire. The type of elastic will affect the magnitude of force placed on the system. In addition, the type of wire (round or square), as well as its diameter will influence the M/F ratio.

If a round wire is used instead of a square wire, there will be uncontrolled tipping, since the tooth can rotate around the wire (the bracket has a square slot while the wire is round) (Fig 44). On the other hand, if a square wire is used, the wire will fill the bracket slot (square into square) (Fig 45). As a result, there is a moment that is created as the tooth is retracted that will counter the moment that would have caused uncontrolled tipping. In addition, the size of the wire will also affect the outcome. A smaller wire will deflect more than a larger wire, therefore bodily movements of teeth are best done with larger wires since they will deflect less and keep their shape, thus guiding the movement.

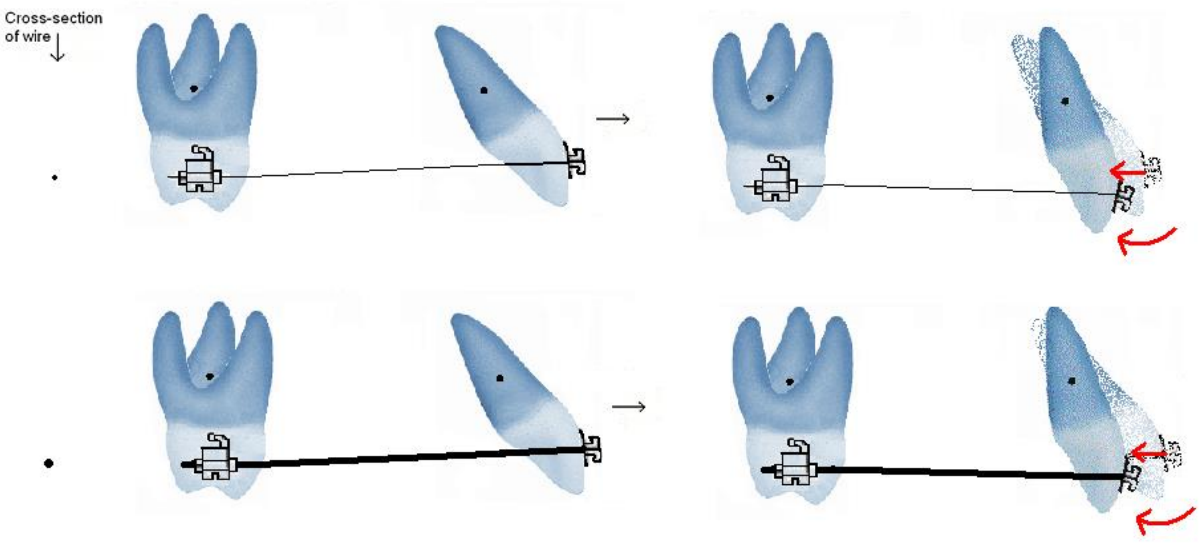


Figure 44: Sliding mechanics (in canine retraction) with a round wire of two different diameters

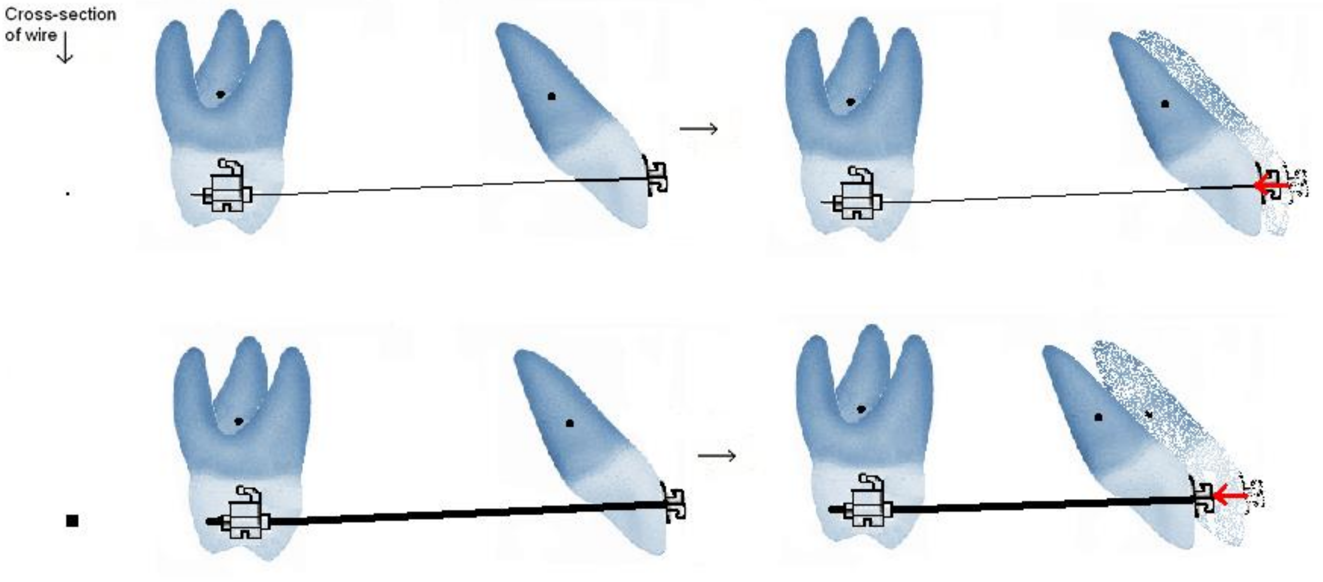
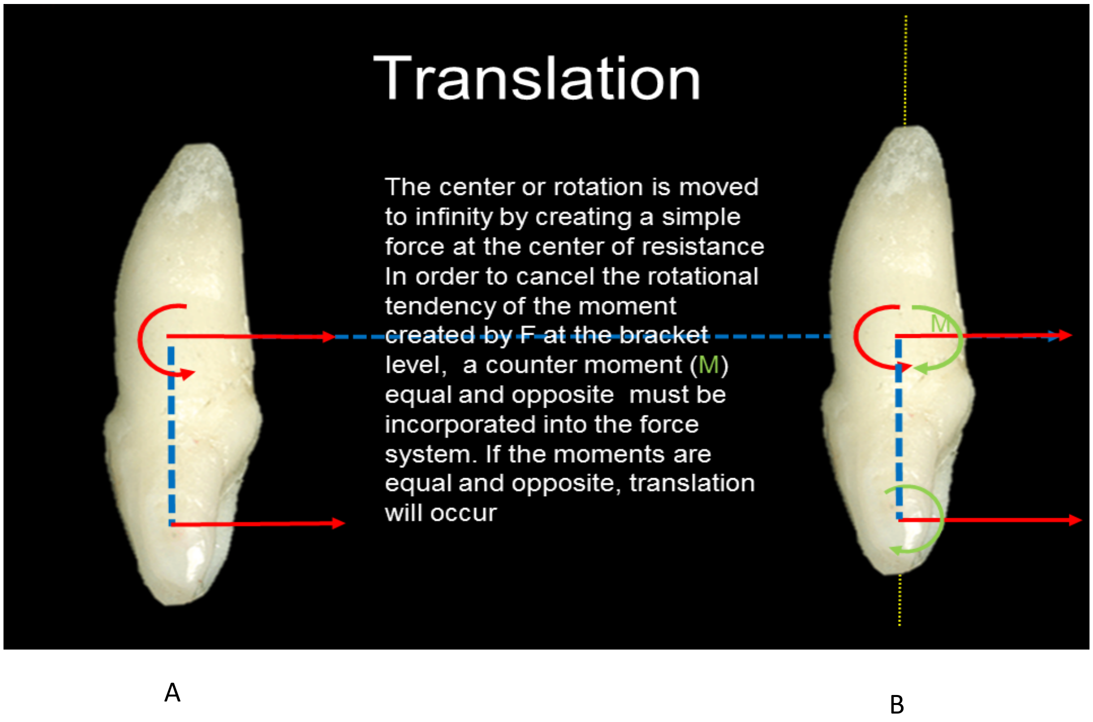


Figure 45: Sliding mechanics (in canine retraction) with a square wire of two different diameters

8.5 EQUIVALENT FORCE SYSTEMS

The problem with the force systems described above is that the forces described are often placed at the centre of resistance. It is impossible to place a bracket at the centre of resistance since it is on the root surface. The solution to this problem is to consider equivalent force systems. Equivalent force systems are when two force systems are equal in all three dimensions (x,y,z), have equal moments and produce the same effect on the object (or tooth). In orthodontics, equivalent force systems produce the same effect whether the force system is placed at the centre of resistance or at the crown (bracket/tube) level.



Translation

The center or rotation is moved to infinity by creating a simple force at the center of resistance In order to cancel the rotational tendency of the moment created by F at the bracket level, a counter moment (M) equal and opposite must be incorporated into the force system. If the moments are equal and opposite, translation will occur

Figure 46: Equivalent force systems example

What kind of force system will produce in B the same effect (translation) as in A, where the force system in B is applied at the crown of the tooth rather than at the centre of resistance as in A (Fig 46)? Using the concepts discussed above, as well as moment to force ratios, we can solve this problem.

Ⓐ

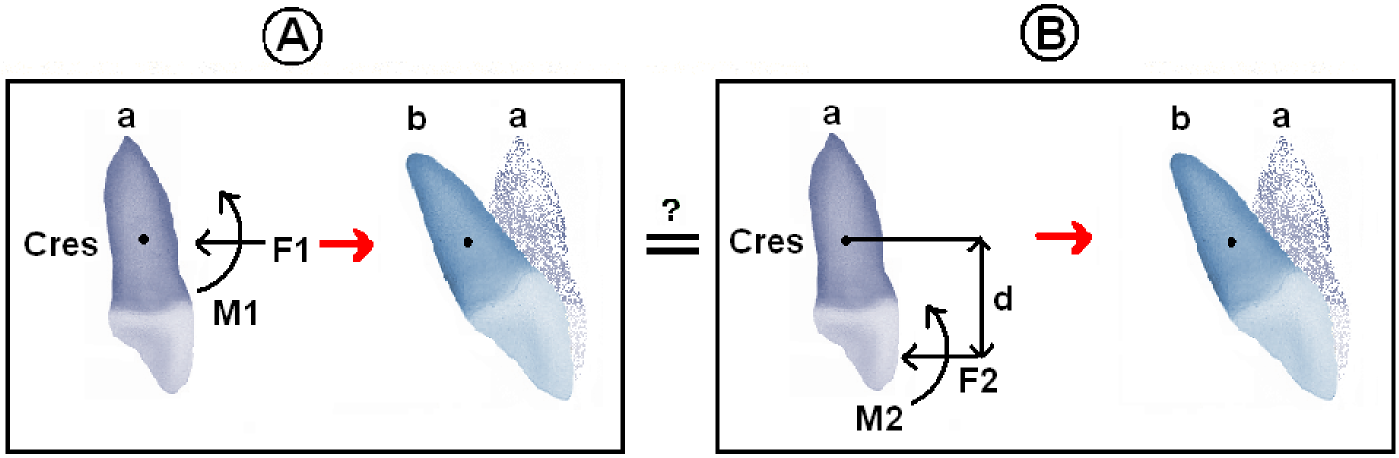
$F1 = -300g$
$\Sigma M = 0$

Ⓑ

$F2 = -300g$
$d = 10mm$
$M = F2 \times d = -3000g\ mm$
(this is the moment produced by the force F2 on the crown of the tooth)

F2 alone would produce uncontrolled tipping of the tooth since there is a moment on the tooth, and the tooth is rotating around the centre of resistance (Crot = Cres). Therefore, to produce a translation movement in System B that is equivalent to System A, a moment at the crown is required that is in the opposite direction to the moment from F2 alone, so that the net moment on System B is zero (as in System A). Hence, the moment is M = +3000g mm.

Example: Consider the equivalent force system required for root movement (Fig 47).



$F1 = -300g$
$M1 = 3000g\ mm$

$F2 = -300g$
$M2 = (M_{F2}) + 3000g\ mm$
$= -(-300g \times 10mm) + 3000g\ mm$
$= 6000g\ mm$

Figure 47: Calculations involved in determining equivalent force systems for root movement

In this example, System A has a force and moment acting at the centre of resistance to produce the desired root movement. In System B, there is a Moment associated with the Force F2 (since F2 is applied at the crown and not at the centre of resistance), which needs to be countered to control the centre of rotation. To produce additional controlled tooth tipping, an additional moment is placed on the tooth so that an equivalent result is obtained in System B, as in System A.

Some hints for controlling movement,

* **It is better to change the moment, not the force**.

a) For controlled tipping, decrease the moment (decrease M/F)

b) For translation, adjust the moment so that you have an equivalent force system

c) Anchor the crown for root movement (i.e. increase the moment)

d) Translation will not occur just by increasing the force on the object.

The M/F at the centre of resistance determines the effect on the PDL. In the area of tensed PDL (away from the direction of tooth movement), bone is deposited, and bone under compressed PDL (towards direction of tooth movement) is resorbed.

Do not forget that the magnitude of the M/F will depend on root length/bony topography (because the distance from the bracket to the centre of resistance can change). For example, shorter teeth require a lower M/F for translation compared to longer teeth.

9 ANCHORAGE

Anchorage in orthodontics is an important consideration since it provides resistance to unwanted tooth movements. Newton's third law is vital to the discussion of anchorage. Recall that every action has an equal and opposite reaction. Therefore, the force system being used to move the teeth will have an equal and opposite reaction on the anchorage system. Anchorage can be intra-arch, inter-arch or extraoral, each providing different magnitudes of stability or resistance to undesirable movements. For example, the teeth, the palate, the neuromusculature, implants, and extraoral structures can serve as anchorage.

The amount of anchorage that is required depends on the treatment plan. For example, to close an extraction space, there are basically three options; retract the anterior segment only (posterior teeth are anchored in place), retract the anterior teeth, and advance the posteriors, or advance the posterior teeth only.

Maximum anchorage can be achieved with the use of implants (micro, mini, palatal), and extraoral appliances (headgears). Maximum anchorage occurs when the anchor unit does not move while the teeth or group of teeth are being moved. This is difficult to achieve with intraoral appliances alone (without implants) because there is always a dentoalveolar response affecting the anchor units. An example of an intraoral appliance that provides a lot of anchorage (although not as much as other maximum anchorage set-ups) is the inter arch Herbst appliance.

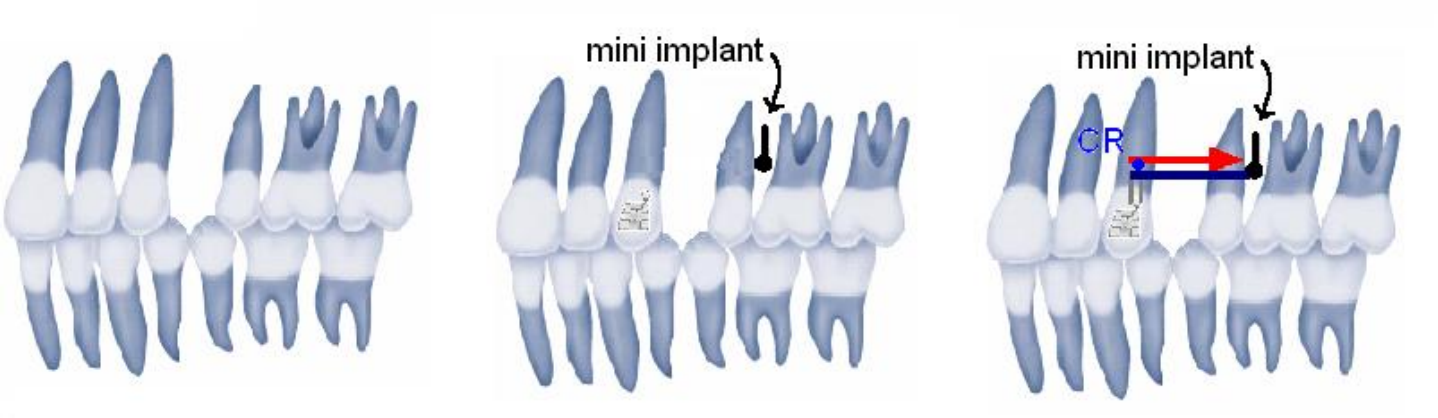


Figure 48: The use of mini-implants in canine retraction

The use of micro-implants is becoming more popular in orthodontics. The following example shows how a canine can be distalized bodily using a micro-implant (Fig 48). In this case, the distal body movement occurs because the force is closer to the centre of resistance. Note that with implants (especially those on the buccal surface of the alveolar bone) there is an undesirable movement towards in another plane (towards the buccal). This can be minimized by the type of wire used in the system (see discussion of wires).

Moderate anchorage occurs when the anchorage unit can be displaced, but less than the teeth that are being moved. Moderate anchorage is usually achieved with intraorally-borne appliance or group of teeth.

Combinations of maximum and moderate anchorage can also be used. For example, in a second premolar extraction case, where we are trying to distalize the first premolar, but want to avoid the mesialization of the first molar, we can anchor the first molar to the second molar. If we were trying to retract the entire anterior segment, additional anchorage would be required, and a headgear could be added. The anchorage of a system can be increased by either increasing the number of teeth being tethered together or by adding extraoral anchorage, depending on the desired outcomes of the treatment.

A situation that does not have an anchorage is reciprocal movement, such as the closure of a diastema (Fig 49).

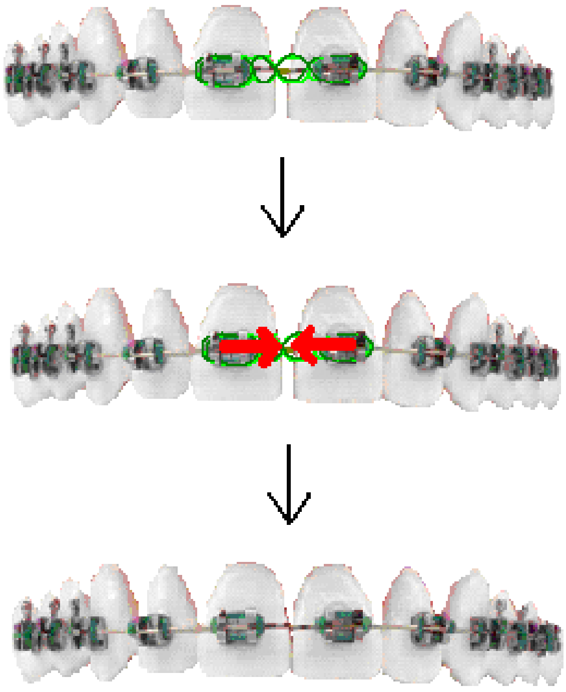


Figure 49: Reciprocal movement in the closure of a diastema

9.1 APPLICATIONS

9.1.1 Canine Retraction

To close the space left after premolar extraction, the cuspid can be retracted initially, followed by the incisors, or alternatively, the six anterior teeth can be retracted en masse. To demonstrate the biomechanics of retraction, this example will use cuspid retraction. The tooth is subjected to a distal driving force along a guiding arch wire. Since the force is occlusal to the centre of resistance, there is a tipping movement of the tooth. This tipping motion is countered with a force couple created by the bracket and the arch wire, resulting in little change in the angulation of the long axis of the tooth. This counter couple depends of course on the size and cross-sectional shape of the arch wire. The wire must fill the bracket slot for the counter couple to occur. The result of this action is a retracted upright canine whose root is parallel to the roots of the adjacent teeth.

9.1.2 Extrusion for CCL and Implant Placement

Clinical applications of tooth movements are a part of orthodontics but are also a part of other specialties. For example, if we want to increase the clinical crown length of a tooth in a situation where we cannot do a periodontal procedure to achieve our goal (for example in the esthetically sensitive anterior area), orthodontic extrusion can be an option. Orthodontic extrusion can be either rapid or slow, depending on the treatment goals, and depending on the mechanics (forces) of the orthodontic appliance used. For example, orthodontic extrusion can be used to prepare a site for an implant.

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