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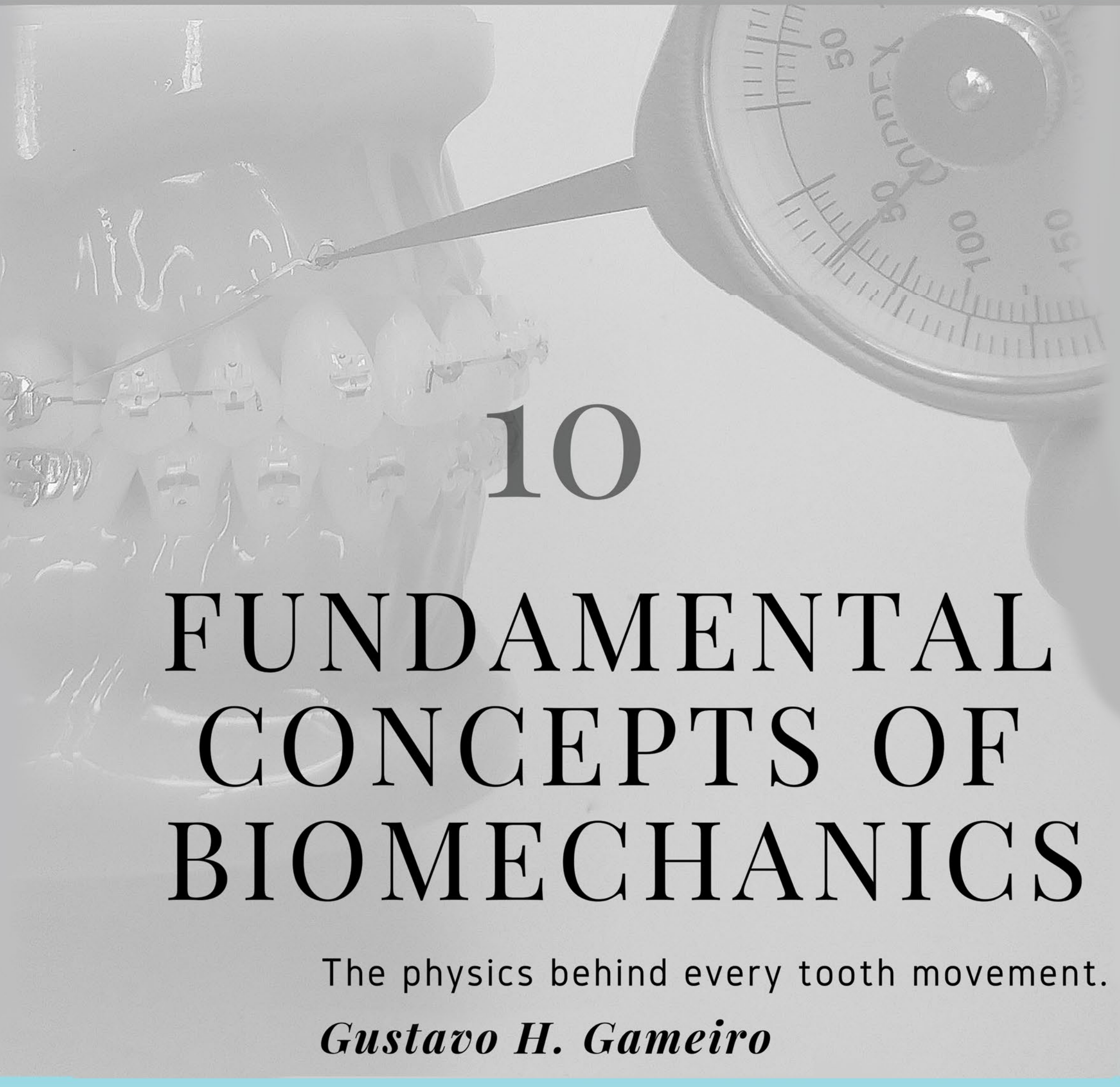

10 FUNDAMENTAL CONCEPTS OF BIOMECHANICS

The physics behind every tooth movement.

Gustavo H. Gameiro

E-book

1st Edition
2019

Acknowledgements

I would like to give special thanks to my English teacher Adriana Gieseler, for proofreading the English version of this material.

Contents

This e-book is highly interactive. The mouse icon will indicate the clickable links.

Introduction

WHY DO WE NEED BIOMECHANICS?

Have you ever met a math teacher who does not understand numbers? An orchestra conductor who does not master musical rhythms? a doctor who does not know physiology?

The answer to these questions is obviously NO. No one is able to imagine a professional who does not comprehend the elementary basics of his practice.

In orthodontics, I believe there is no doubt about the fundamental laws governing any tooth movement. I am referring to the exact and immutable laws of PHYSICS and BIOLOGY, which form the pillars of ORTHODONTIC BIOMECHANICS.

Biomechanics is relentless; it is always present in our treatments, both in successes and failures. Its principles will always govern our treatments, its definitely not a matter of choice. Our best option, therefore, is to know and master these principles, so that we can control the outcome of our cases.

ARE YOU IN CHARGE?

The major difference between an "arch changer" and an orthodontist is the knowledge of biomechanics. While the former resembles an airplane pilot who only knows how to use the automatic mode, the latter is the one capable of having full control of the aircraft in both modes, automatic and manual.

"YOU and not the wire should do the THINKING". Prof. Charles J. Burstone

About the author

THE HARD WAY OF LEARNING

Before presenting my academic titles, I would like to briefly refer to my journey of education in Orthodontics, since my academic career is a reflection of the reasons why I´ve created the ESSENTIAL BIOMECHANICS educational platform .

My reflections

I´m sorry for this simple analogy, but there were moments I felt a bit lost. Even having a definite dream, it was very difficult to achieve my goals without support.

I consider this the hard way of learning. I had to enter in a very competitive academic career* in order to have access to a qualified knowledge and formation. But what about all the colleagues that don't want to follow an academic career, that have chosen to became specialists on clinical practice?

This ponderation made me realize that we need to reduce the gap between scientific knowledge and clinical practice.

This is our mission!

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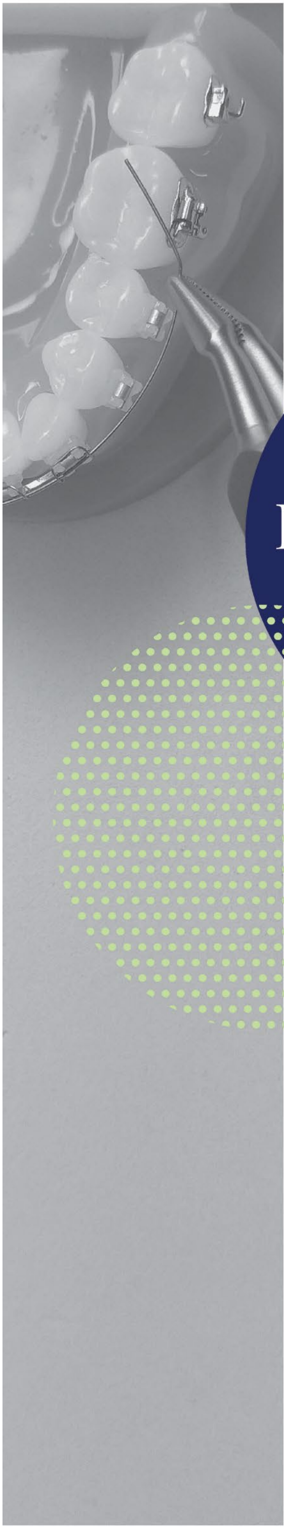
Associate Professor at Federal University of Rio Grande do Sul, Brazil
Creator of the blog Essential Biomechanics

"If you want to go fast, go alone. If you want to go far, GO TOGETHER". African Proverb



Fundament I

I- There is only one drug of choice for tooth movement, and it is called force system.

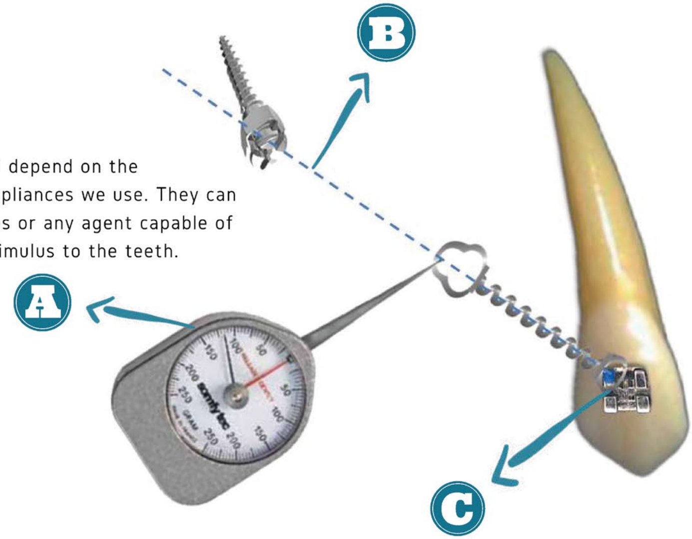
The orthodontic force

FORCE AND ITS ATTRIBUTES

In medical treatments, doctors have to decide among thousands of drugs to achieve the best results. In orthodontics, we have only one available ”drug”: the orthodontic FORCE. However, we need to control the “dosage” of this drug in order to get the desirable dental movements. Force magnitude (A), direction (B) and point of application (C) are some variables that must be manipulated to achieve an efficient treatment.

The most important parameter of all is the line of action of force, which in this case can be easily visualized by the spring itself.

The force magnitude will depend on the characteristics of the appliances we use. They can be springs, elastics, wires or any agent capable of applying a mechanical stimulus to the teeth.



The point of application represents the point of contact of our appliance with the tooth to be moved. Whenever possible, this decision is made by the professional.

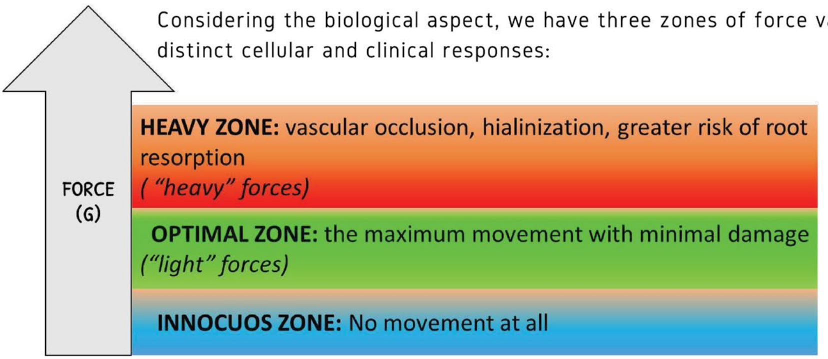
Click HERE to see a whiteboard animation about the attributes of force.

Optimal force values

THE SEARCH FOR THE IDEAL FORCE

The classic concept of optimal force was proposed by Scharws in 1932, when describing that the optimal force would be the one capable of altering tissue pressure without occluding the blood vessels of the periodontal ligament. According to him, forces below this level would not induce tooth movement, whereas forces above this level would provoke areas of tissue necrosis, which would hamper movement until undermining resorption removes necrotic tissues.

Considering the biological aspect, we have three zones of force values, with distinct cellular and clinical responses:



Theoretically, the term LIGHT is used for forces that are within the optimal zone range. However, it is very difficult to establish the real numerical differences between a light and a heavy force in the clinical practice. For example, if we apply a force considered light, such as 25g, in a smoother and homogeneous alveolar ligament-bone interface, this force will probably not cause much damage and tissue strains, being therefore considered LIGHT from the biological aspect. However, if this same force is applied in a more irregular and rough ligament-bone interface, for example, the tissue strains will be larger, leading this force to be considered HEAVY in this situation.

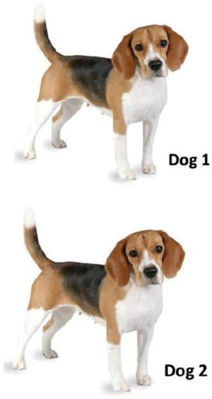
Click HERE to see a full video lecture about the "ideal" orthodontic force.

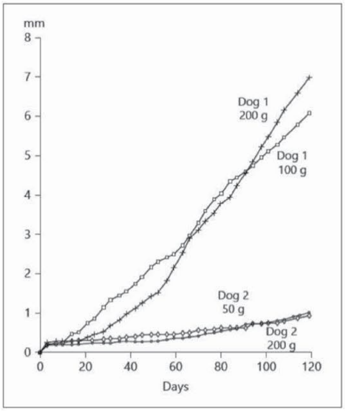
Interindividual differences

OPTIMAL INDIVIDUALIZED VALUES

It is necessary to understand that the impact of force magnitude on tissue responses depends on a number of factors, such as type of movement, root size and morphology, support tissue conditions, local cell population, and the ability of cellular responses to adapt to these stimuli. These are the main factors that explain the enormous individual differences we observe in clinical practice, such as varied pain responses, degree of mobility, speed of movement and root resorption risks.

The interindividual differences are more important than the magnitude of the force. Take, for example, this classic study on dogs. This research* evaluated the influence of several magnitudes of force on the amount of dental movement:





In dog 1, doubling the force did not change the amount of movement (100g vs. 200g).

In dog 2, the tooth movement obtained was the same even with the force being increased 4 times (50g vs. 200g).

Also notice in this graphic, the enormous difference of movement observed between dogs 1 and 2, independently of the intensity of the applied force.

"The interindividual differences are more important than the magnitude of the force".

*Pilon JJ, Kuijpers-Jagtman AM, Maltha JC Magnitude of orthodontic forces and rate of bodily tooth movement. An experimental study. Am J Orthod Dentofacial Orthop. 1996;110:16-23.

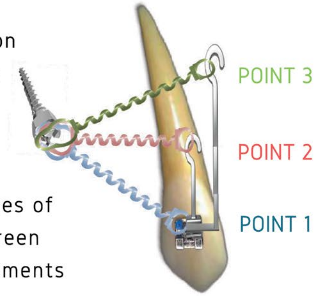
Force's line of action

THE SUPREMACY OF THIS PARAMETER

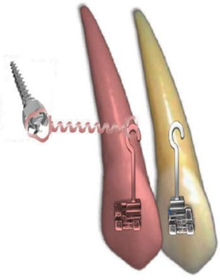
A professor once taught me that the orthodontist should act as a `line of action hunter`. I really appreciated this analogy, because this is actually what we do whenever we want to perform a controlled tooth movement. In order to predict the resultant tooth movement of any appliance, one of the first questions we should ask ourselves is: which line of action would induce the movement I want to achieve?

For example, let´s suppose we select 3 distinct application points, which also establish three different lines of force action in this particular case. Do you think the resulting movements would be similar?

The answer is obviously no. Since we have 3 different lines of force in each situation (represented by blue, red and green coils), we can certainly predict three distinct dental movements according to the chosen line of action.



With the blue coil, we would have a tipping movement in which the crown would move more than the root, and the tooth would undergo slight intrusion.



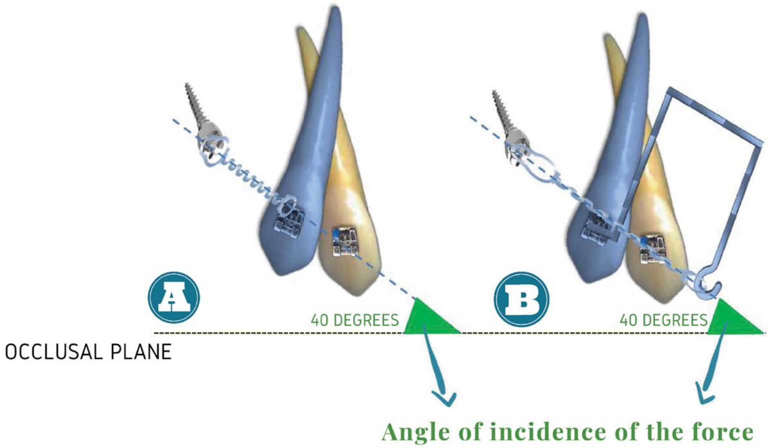
With the red coil, the tooth would move with minimal change of its long axis, and without significant change in the vertical direction.

With the green coil, we would cause slight extrusion, and greater root movement.

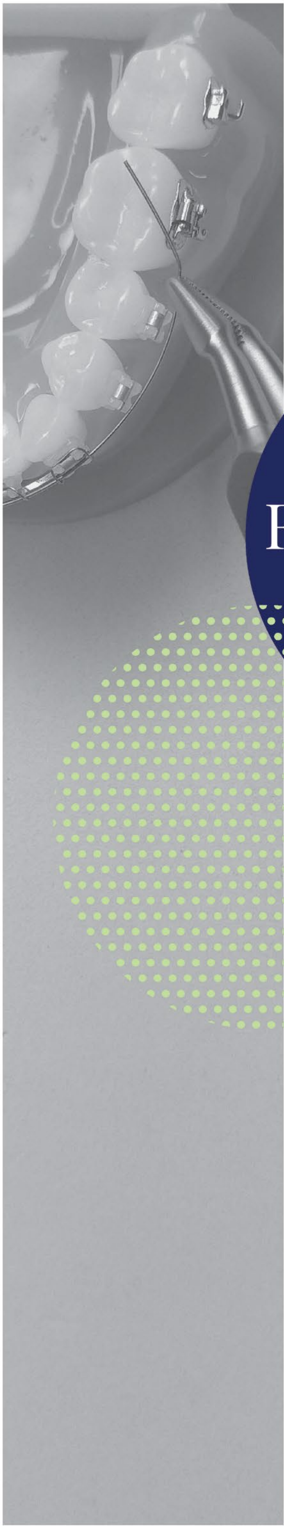
The law of transmissibility

In short, the law of transmissibility states that distinct points of application along the same line of action of force provoke exactly the same effects.

For example, if instead of inserting your spring directly into the bracket (Figure A), you decide to create an appliance configuration to apply the force at a point ahead the previous one, but in the same line of action (Figure B), your movement will essentially be the same.



We can analyze the inclination of the force´s line of action in relation to some reference plane. If our reference is the occlusal plane, for example, we will see that the line of action of the force lies at 40 degrees of it in both situations A and B. This angle can be called the angle of incidence of the force.



Fundament II

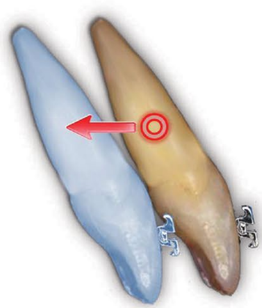
II- The center of resistance constitutes the direction sensor of the resulting movement.

Center of resistance

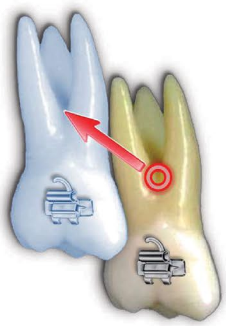
"YOU ARE ALWAYS ON MY MIND"

In the past, some philosophers believed that the heart was the housing of the human soul. Nowadays, I suggest that we could use a similar analogy regarding teeth. I mean, we could consider that every tooth (or group of teeth) have its most relevant part concentrated in a restricted area - the center of resistance (CR). In this metaphor, the CR constitutes the 'heart' of the tooth, its most important part, a special sensor, and thus we should always look at it while making our movement predictions.

DEFINITION: Orthodontic literature defines CR (red circle) as the point at which forces cause the parallel movement of all points of the tooth. This type of movement, as we will see next, is called translation or bodily movement.



Translation can occur in any direction, provided that every part of the tooth moves parallel with a force vector. In the figure, we can see a horizontal translation of the incisor, and an oblique translation of the molar.



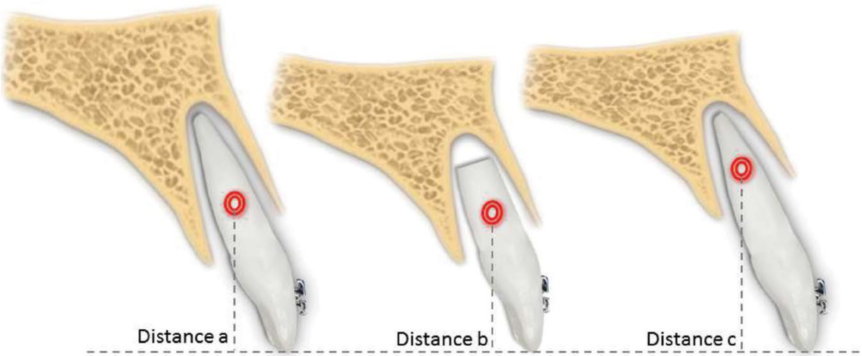
LOCATION: In a monoradicular tooth, CR is usually located between the cervical and middle thirds of the distance between marginal ridge and apex. In multiradicular teeth, CR is commonly found in the apical part of the bifurcation or trifurcation of the roots, depending on the evaluated tooth.

The CR is not a single point, so it is usually represented in diagrams by a large circle.

The localization of CR depends on a number of factors

The CR locations mentioned in the literature usually apply to teeth with normal root anatomy, and with adequate bone support. However, we need to be aware that the location of CR depends greatly on the root structure and conditions of the supporting tissues. Let's see:

In a normal central incisor with good bone support, the CR is usually located at a distance of 10 mm from the center of the clinical crown, where we bond our brackets (distance a). However, if this incisor shows a severe root resorption, this distance will be significantly lower (distance b). On the other hand, if the patient presents a loss of alveolar bone, the CR will be located closer to the apex, and more distant, therefore, from the bracket (distance c).

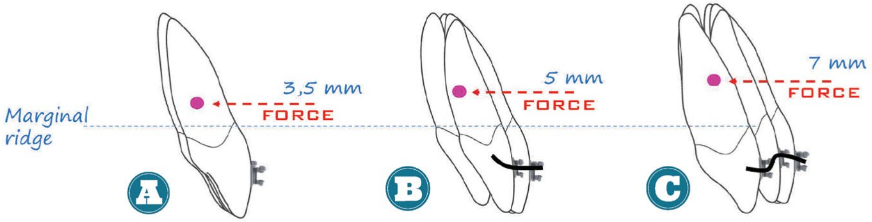


Orthodontists dealing with periodontally reduced dentitions need to understand that the CR of these teeth moves to a more apical position.

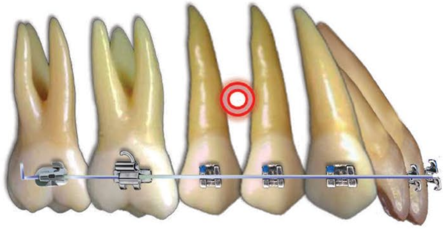
Teeth connected by a rigid wire behave as a single unit

In clinical practice, we usually form groups of dental units by joining the teeth with segments of rigid wires. What should be clear to the professional is the fact that each group of teeth has its specific CR in these cases.

For example, if you want to perform a translational retraction of only two upper central incisors, the height indicated for your force line of action should be 3.5 mm above the marginal ridge. The reason for it is that this is the estimated CR height of this group of 2 teeth, considering a normal bone support* (Figure A).



However, if you need to retract the 4 upper incisors, your line of action should rise up to 5 mm from the marginal ridge, because this is the estimated height of the CR of a group of 4 upper incisors (Figure B). And finally, if you want to try translating the 6 anterior teeth simultaneously, your line of action should rise up to 7 mm above the marginal ridge (Figure C).



ALWAYS CONSIDER THE CR OF THE GROUP YOU WANT TO MOVE!

If you think of an upper dental arch joined by a rigid wire, either conjugated or attached to the omega loops, we can estimate the behavior of this group of teeth as if it were a single unit. And in the case of the upper arch, it is estimated that its CR is located between the roots of the premolars.

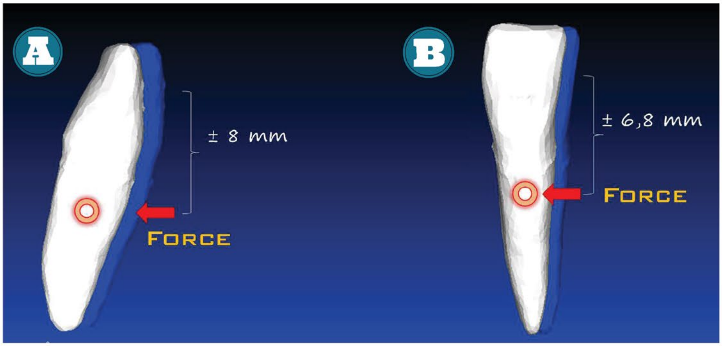
*Bulcke et al. Location of the centers of resistance for anterior teeth during retraction using the laser reflection technique. Am J Orthod Dentofacial Orthop. 1987;91:375-84.

The CR varies according to the direction of movement

In addition to the factors previously mentioned, such as radicular structure, degree of alveolar bone support and number of grouped teeth, another important factor to consider in the estimation of the CR is the direction of the movement performed.

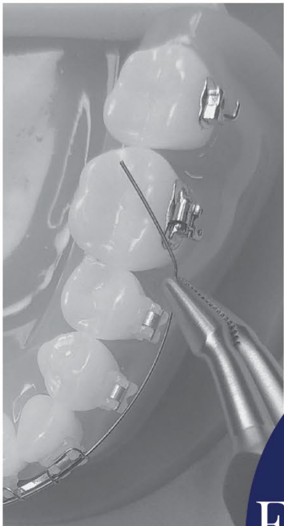
For example, if you want to translate this lower incisor in the buccolingual direction, the CR is commonly about 8 mm from the bracket (Figure A).

However, if you wish to make a body movement in the mesio-distal direction, considering this same tooth, the CR will be located a little more to occlusal, compared to the previous movement (Figure B).



EXPLANATION: The figure clearly demonstrates that the resistance to the buccal-lingual movement is greater than the resistance to distal movement. Why? Because the roots of these teeth are more tapered in the mesio-distal direction.

We need to consider the CR as a three dimensional area for a proper dental movement planning.



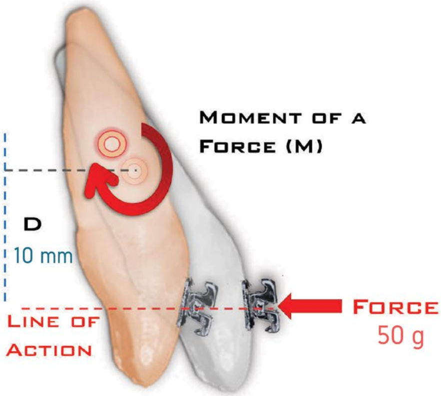
Fundament III

III- Appliances are just tools for generating forces, moments of a force and couples.

Moments

Whenever there is a distance between the line of action of our force and the center of resistance of the teeth, they will present a tendency of rotation, which we call MOMENT.

The orthodontic literature defines moment as the mathematical representation of the rotation tendency of a body around its CR. We can simplify it as being the rotation tendency of a body. It is usually illustrated by a curved arrow, which indicates the direction of the moment.



The moment of a force is calculated by multiplying the force by the perpendicular distance between the tooth's CR and the line of action of the force itself.

$$M = F \times D$$

If we apply a lingual force of 50 g in the bracket level, with the action line located 10 mm from the tooth's CR, this tooth will receive both the distal force and the moment generated by this force. In this case, applying the formula (M=FxD), we would have generated a moment of 500 gmm, clockwise.

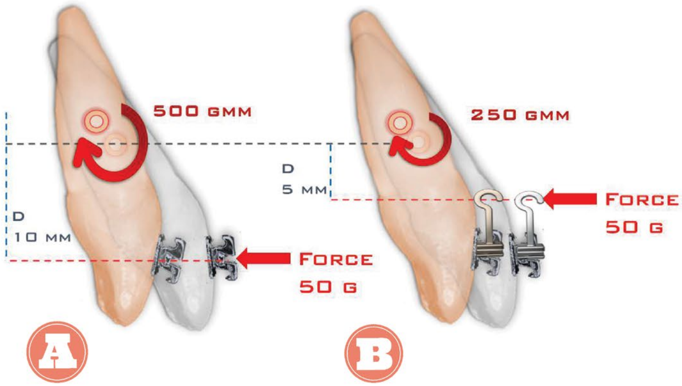
There are two ways to generate moments in orthodontics

I ask your attention to this point of the book, because the two possible ways to generate moments in orthodontics constitute our day-to-day clinical practice.

1) MOMENT OF A FORCE

The first way to obtain moments in orthodontics is by the application of a force at a point distant from the tooth's CR, as explained in the previous page.

In this case, the moment is called the moment of a force. It is clear that this type of moment depends both on the magnitude of the force, and on its point of application and direction.



A lingual force of 50 g in the bracket of figure A generated a moment of 500 gmm, clockwise. However, if we apply that same magnitude of force to a point whose force line of action is 5 mm from the CR, as in figure B, the generated moment will be 250 gmm (M=FxD).

"The moment of a force depends both on the magnitude of the force, and on its point of application and direction".

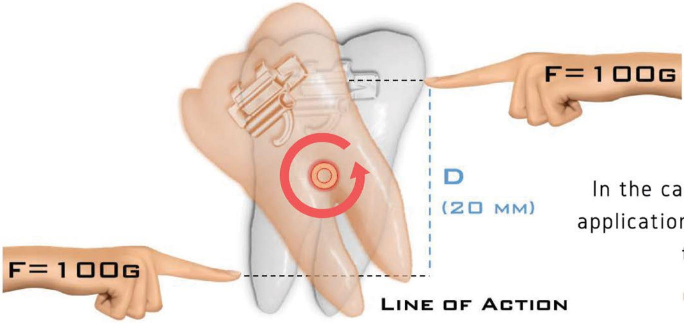
There are two ways to generate moments in orthodontics

I ask your attention to this point of the book, because the two possible ways to generate moments in orthodontics constitute our day-to-day clinical practice.

2) MOMENT OF A COUPLE

The second way of producing moment consists in the application of two parallel (non-coincident) forces of equal magnitude and opposite directions. In this situation, we have a couple, which generates a special type of moment, called the MOMENT OF A COUPLE.

This special type of moment can also be called either a pure moment or a couple. Whenever a couple is applied to a body, this body rotates along its center of resistance (CR).



In the case of a tooth, therefore, the application of a couple would rotate the tooth around its CR.

The resulting force in this case is zero, because the opposing forces have cancelled each other. Although it seems strange that we can move teeth with no resultant force, this is absolutely possible by the application of a couple.

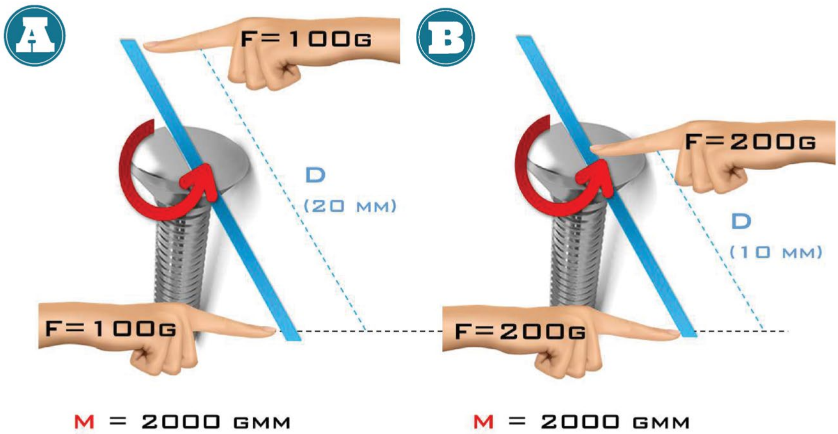
The moment of a couple can be calculated by multiplying a force by the distance perpendicular to the other force. In our example, if this distance is 20 mm, we will have a moment of a couple of 2000 gmm, in counterclockwise direction (M= F x D).

"There are two types of moments in orthodontics: the moment of a force, and the moment of a couple".

Couples act as free vectors

IT DOES NOT MAKE ANY DIFFERENCE WHERE THE COUPLE IS APPLIED

I would like to emphasize a very important principle about couples, which states that these are free vectors. That is, the point of application of the couples does NOT interfere with its final effects, as long as we maintain their magnitude and direction.



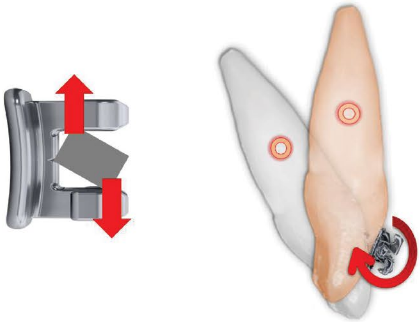
Suppose you want to apply a moment of 2000 gmm in counterclockwise direction, in order to loosen this screw. There are different ways to get the same effect. If you apply two opposing forces of 100 g considering that they are 20 mm apart from each other, you will produce your desired moment of 2000 gmm (Figure A).

You will get exactly the same result if you choose to apply two opposing forces of 200 g at different points, and at distance of 10 mm between them. Since the magnitude and direction of the moment of the couple are the same, the final effect on the screw will be suchlike (Figure B).

Couples act as free vectors

THE CR DOES NOT KNOW WHERE THE COUPLE IS APPLIED

Although the point of force application is critical for producing different types of tooth movement, couples can be applied anywhere on a tooth.



Some orthodontists have believed that a couple (eg. torque) causes a tooth to rotate around the point of application of the couple .

This is wrong! This misunderstanding can lead to a significant false prediction of the resultant tooth movement, such as in this figure.

TESTING YOUR CLINICAL EYE: If you apply equal couples in three distinct regions of the same tooth, do you think the tooth will respond differently in the 3 situations ?

Keep in mind that the moment of a couple constitutes a free vector, thus the resulting movements in the 3 situations would be the same!

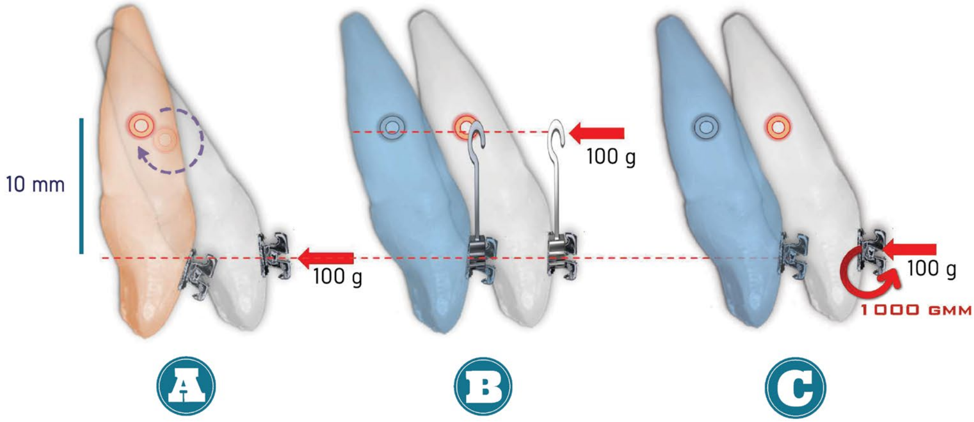
Forces and moments are all we have

APPLIANCES ARE TOOLS USED TO APPLY FORCE SYSTEMS

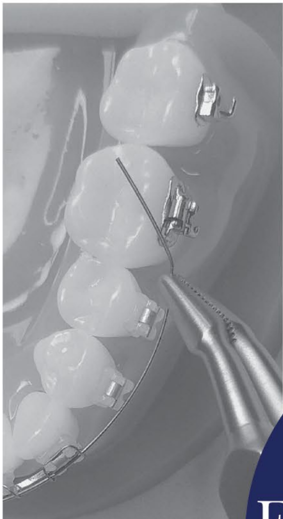
You can use or create any imaginable appliance, it can be it fixed, removable, conventional, lingual or even "invisible". The fact is that ALL of them will always be governed by the exact and immutable laws of physics. At the end, our appliances will move teeth by the application of a force system, which consists in forces, couples, or a combination of them.

As we have seen, the application of a single force distant to the CR will produce a moment of a force, which in turn will cause some tooth rotation (Figure A).

If you do not want any rotation, two alternatives are possible: 1) you can try to apply a force that pass through the CR (Figure B); 2) or you can try to neutralize the moment of a force (clockwise direction, in purple) by adding a counterclockwise couple applied to the bracket (in red, Figure C).



Our clinical life turns around the application of forces and moments in order to obtain controlled tooth movements.



Fundament IV

IV- Equivalent force systems produce the same effects.

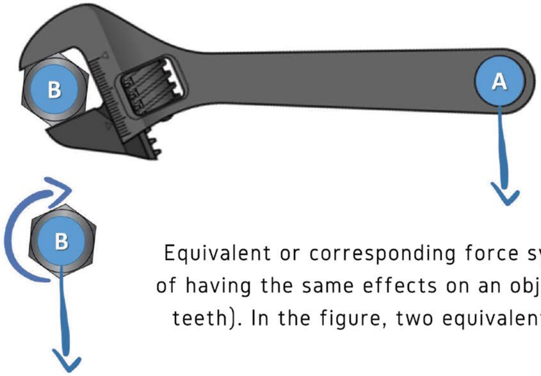
Equivalence of forces

THE HEART OF THE TOOTH INDICATES ITS MOVEMENT

After presenting the basic concepts of the force systems, we will start understanding how can we predict the resultant tooth movement from any type of appliance. The first analysis you should do is: when applying a force to any point on a tooth, what are the forces and moments perceived by the center of resistance (CR) of that tooth or group of teeth?

It is this answer that will point the direction that will result from your movement. I mean, if you know what does the CR feel, you´ll know how the teeth will move. Just as the cardiologist is focused on the heart of a patient, we should always be focused on this special sensor of a tooth - the CR.

The main difficulties we have to predict and control tooth movements are related to the fact that we usually apply force systems on points located distant from the tooth´s CR. Therefore, we must understand how to apply the principle of EQUIVALENCE in order to produce accurate movements.



Equivalent or corresponding force systems are those capable of having the same effects on an object (eg. tooth or group of teeth). In the figure, two equivalent systems are illustrated.

Forces that are interchangeable are called equivalent. In other words, the effect on teeth or arches is the same.

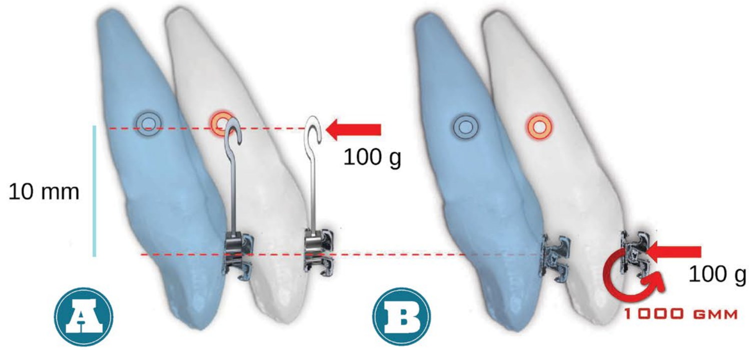
Equivalence in orthodontics

HOW TO VERIFY THE EQUIVALENCE OF FORCES

There is a simple formula to verify the equivalence between two systems of forces. It is enough that 2 requirements are met:

1) The sums of their forces must be equal ($\Sigma F1 = \Sigma F2$).
2) The sums of their moments around ANY point must also be equal ($\Sigma M1^* = \Sigma M2^*$).

Let´s take an example: If a 100 g lingual force is applied on a wire extension attached to the bracket, the line of action will pass through the CR, and thus a bodily movement is obtained (Figure A).



In order to obtain the same effect in Figure B, the CR on B must feel an equivalent force system in relation to Figure A. Therefore, the resultant force must be the same (100 g to the lingual), and the resultant moment at CR* (our point of convenience) must also be the same. If the moment at CR in Figure A is equal to zero (100 g X 0 = 0 gmm), in Figure B a counterclockwise couple of 1000 gmm was added to the bracket to neutralize the moment of a force (clockwise, arrow not shown) created by the force applied 10 mm from the CR.

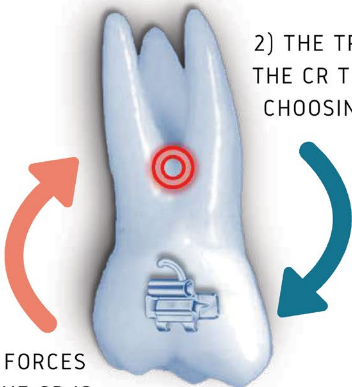
The force systems in A and B do the same - the teeth will not notice any difference. The systems are equivalent!

Equivalence in clinical practice

EQUIVALENCE EVALUATION HAS TWO MAIN OBJECTIVES

We, orthodontists, evaluate the equivalence of force systems basically with 2 main objectives: 1) the transference of the forces that we apply in the brackets to the CR of the teeth; and 2) the transference of forces from the CR to the brackets.

2) THE TRANSFERENCE OF FORCES FROM THE CR TO THE BRACKETS IS USEFUL FOR CHOOSING OR CREATING A PARTICULAR MECHANICS.



1) THE TRANSFERENCE OF FORCES FROM THE BRACKETS TO THE CR IS VERY USEFUL FOR PREDICTING TOOTH MOVEMENT.

The two types of transference should be done in 2 steps:

1) First, you transfer the force directly from the point of application (eg. bracket) to the CR (or vice versa), maintaining the same intensity and direction. The transfer is simple and straightforward.

2) In the second step, you must add the possible moments of the system.

Click HERE to see a whiteboard animation about the equivalence of forces.

Equivalence in clinical practice

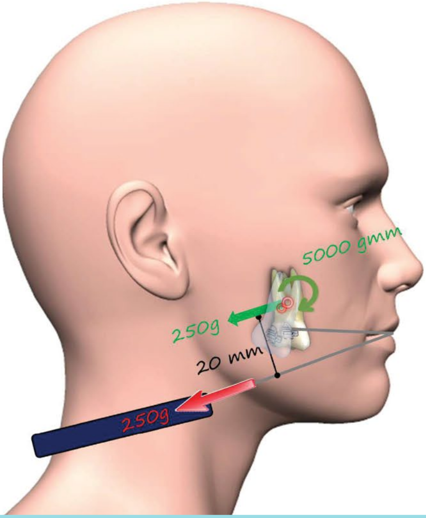
TRANSFERING FORCES FROM BRACKETS TO THE CR

This type of transference is extremely useful in predicting tooth movements, resulting from the action of any orthodontic appliance. Let's use the example of an extra-oral appliance:

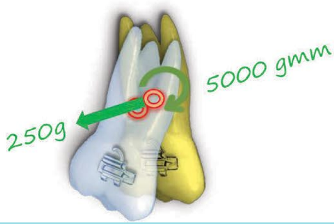
Suppose you apply a cervical traction force, with a magnitude of 250 g, with the line of action lying 20 mm from the CR of the molar. In order to estimate the resulting movement of the tooth, you need to initially transfer the forces applied to the device to the CR.

This transference should be done in the 2 steps previously mentioned:

1) First, you transfer the force directly from the point of application (the molar tube) to the CR: If you applied 250 g with an angle of incidence of 30 degrees in relation to the occlusal plane, this same force (red force), and with the same direction, will also be perceived by the CR (green force).



2) In the second step, you must add the possible moments of the system: In this case, as the force was applied at 20 mm from the CR, it is clear that there is a moment of a force of 5000 g mm clockwise (M=FxD). The resultant tooth movement would be the slight extrusion and the distal inclination of the molar crown (what does the tooth´s heart feel?).



Realize that we replaced one force system (a simple force, in red) by another (a force and moment around the CR, in green).

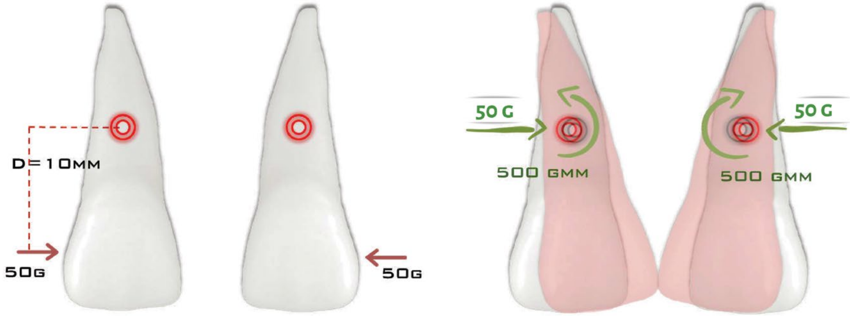
Equivalence in clinical practice

THE CR INDICATES THE RESULTANT TOOTH MOVEMENT

The verification of the equivalence of force systems in orthodontics should be a constant and almost automatic practice during our biomechanical planning. Let´s see another example, so you can get familiar with this reasoning.

Suppose you want to close a central diastema by using clear aligners.

In this first example, the application of a single force at the distal surface of the tooth will not produce an appropriate result. By transfering the forces to the CR, we can notice that it will perceive both a force (desired) and a moment of a force (undesired). This force system will tip the crowns mesially, creating a gingival black triangle, which is generally considered to be aesthetically unacceptable.



Following the 2 steps for transfering the forces from point of application to the CR:
1) The force (50 g) is transfered directly to the CR.
2) Then, you must add the moments of a force of 500 g mm (M=FxD) to each CR.
The right tooth will receive a counterclockwise moment, and the left tooth a clockwise one.
The resultant tooth movement would be an uncontrolled tipping. As always, the tooth´s heart (CR) dictates the resultant movement!

Equivalence in clinical practice

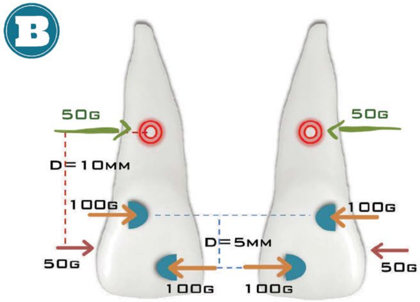
TRANSFERING FORCES FROM CR TO THE APPLIANCE

In order to avoid the undesired result of the previous example, let´s try a different approach. By using the same reasoning of equivalent systems, we can select a specific force system to obtain our desired movement.

To do that, just follow the same steps seen in the previous example, but in the opposite direction. This analysis is very useful for choosing or creating a particular mechanics.

Suppose your final goal is to close a central diastema by mesial translation. To do that, the resultant force system at the CR should be a mesial force, without any rotations (Figure A).

How can we get this movement with an aligner? By replacing the force system at CR with an equivalent one applied at the crown level (Figure B).

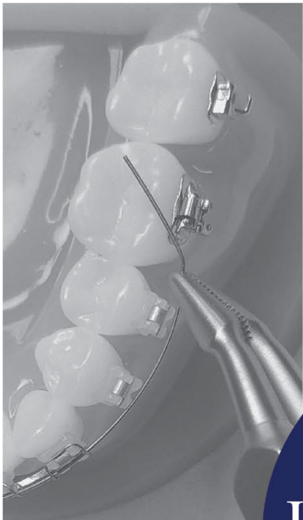


The 2 steps to transfer the forces from CR to the appliance are:

1) The force (50 g) is transfered directly to the point of application (red straight arrow).
2) The magnitude of the moments (in this case, the yellow couples*) was established multiplying the original force magnitude by the distance from the CR to the selected point of application, measured perpendicularly to the line of action of the force (M=50x10=500 g mm).

For a practical exercise, you can transfer your planned force system (the aligner forces) again to the CR. You will notice that the moments of a force (in red) were cancelled by the moments of a couple (in yellow). At the end, both CRs will perceive only the mesial forces (Figure C).

*The attachments used to apply this type of couple with aligners are called mesiodistal root movement optimized attachments.



Fundament V

V- The moment to force ratio represents the dosage of your force system.

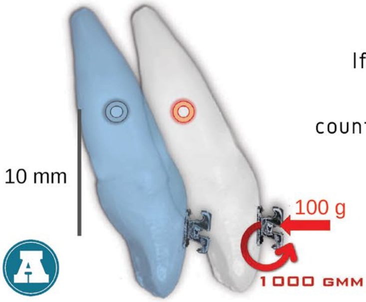
Moment to force ratio

THE MAIN SYMPTOM OF THE TOOTH'S HEART

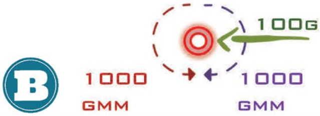
Considering our analogy of the tooth´s center of resistance (CR) as the tooth´s heart, we could say that the most important symptom perceived by this part is the moment to force ratio.

This term is constantly used in the orthodontic literature to explain the mechanical actions of the appliances, and the types of resulting movements. Regardless of the technique you use, the application of this concept is universal, so it pays off concentrating on its study.

The MOMENT TO FORCE RATIO, or simply M/F, as the name implies, represents the ratio of the moment (produced by a force, a couple, or both of them) to the force applied to a specific part of a tooth.
It is very important to understand that the term can be used to describe the M/F perceived by the CR (M/F at CR) and the M/F applied at the bracket (M/F at bracket).



If we take our classic example of an incisor translation, produced by the combination of a lingual force and a counterclockwise couple, the M/F at the bracket is equal to 10 and the M/F at the CR is equal to 0 (Figure B).



The resultant moment at CR is 0 because the moment of a force (purple) was neutralized by the moment of a couple - the torque (red). Therefore, M/F at CR = 0.

As always, the tooth´s heart symptom - the M\F at CR - dictates the resultant movement!

Fundament VI

VI- The location of the center of rotation assists in the choice of the appropriate force system for each type of movement.

Center of rotation

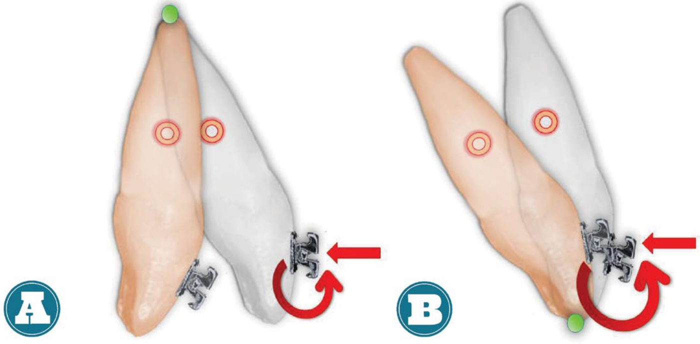
AN AUXILIARY TO VISUALIZE THE TOOTH MOVEMENTS

After presenting the basic elements necessary to understand how teeth move, we will describe an important concept used to analyze the different types of tooth movements - THE CENTER OF ROTATION.

The establishment of a center of rotation (CRot) in two dimensions represents an useful method for the clinician to visualize the tooth movements. Moreover, we can relate specific CRots to specific M/F ratios at the bracket or at the CR in order to select the best appliance for our planned movements.

THE CONCEPT:

The center of rotation represents the point around which the tooth rotates when it is moved. This point may be located inside or outside the tooth, and is usually recorded in two-dimensional projections.



Notice that specific CRots (green circle) are related to very different tooth movements. In A you can see a controlled tipping, and in B a root movement.

Center of rotation

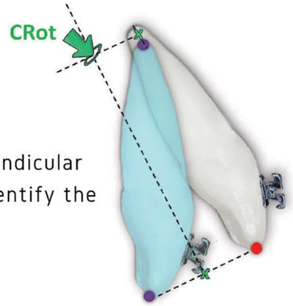
HOW TO FIND IT

Usually, the center of rotation can be found in 3 simple steps:

Let's use an example in which the tooth has left position A (white tooth) to B (blue tooth):

1) The first step is to identify 2 reference points on the teeth. I suggest you use one point at the incisal edge and another at the root apex. Mark these points on the teeth both before and after the movement.

2) Now connect the before and after points with a line and identify your midpoint.



3) Finally, from this reference, draw two perpendicular lines and the intersection of these lines will identify the center of rotation of the movement.

Click HERE to see a video about the center of rotation. A whiteboard animation explains how to find this point in 2D.

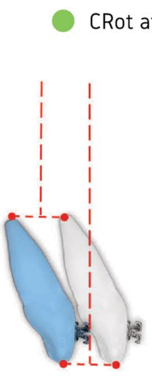
Center of rotation

LOOKING FOR CROTs IN CLINICAL PRACTICE

In orthodontics we have infinite possibilities to move teeth, in varied directions according to the need of the case. Let´s see some clinical examples in order to practice the visualization of the CRot in different movements.

In this first case, our goal was to retract the incisors while maintaining their inclinations - the so called bodily movement. What type of mechanics should be appropriate for that purpose? an appliance by which the line of action could pass through the CR of the six anterior teeth would apply the ideal force system at CR.

Considering that it was not practical to place a force so far apically, we used a mini-implant for the distalization force, along with torque control in order to obtain the bodily movement of the six anterior teeth (en-masse retraction).



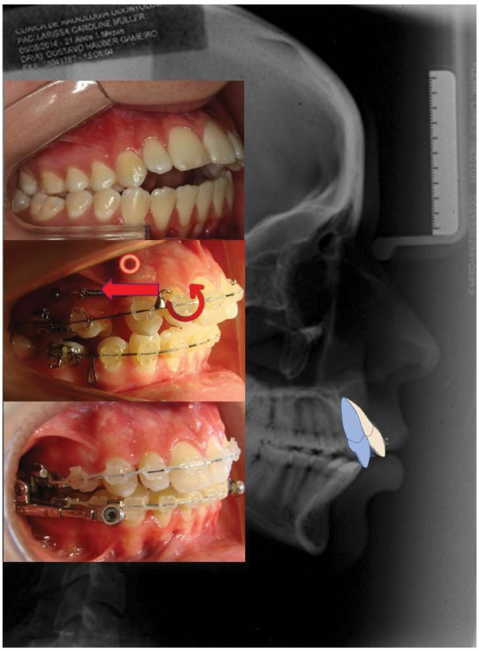
It is impossible to find an intersection between the perpendiculars from the trajectories of the movements. Therefore, in these cases of translation, it is said that the center of rotation is located at infinity.

Notice that we´ve used the principle of equivalence to create a force system at the bracket (a force+a couple at the bracket) equivalent to the ideal system at the CR.

Center of rotation

LOOKING FOR CROTs IN CLINICAL PRACTICE

In this second case, where we aimed at a distalization with a minimum of root movement (controlled tipping), mini-implants were used with a different line of action, and again with appropriate torque control in order to obtain the desired movement.



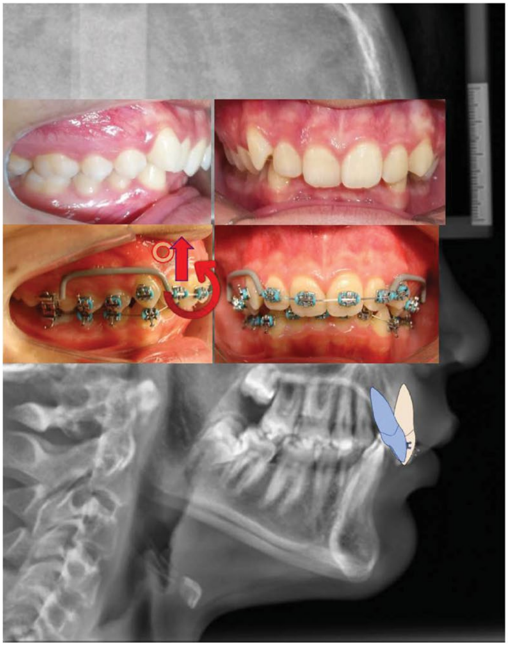
The moderate couple (torque) applied at the bracket was needed to avoid proclination of the root apex during the retraction.

Notice that we can easily find the center of rotation at the apex. In this case, the CRot represents a point of the tooth that did not move.

Center of rotation

LOOKING FOR CROTs IN CLINICAL PRACTICE

In this third case, we exemplified an inverse situation of the previous one, in which we idealized a movement of the incisors with the maximum of root movement. This case required a significant counterclockwise couple. This torque, combined with an intrusive mechanics was applied to the four incisors by an utility arch of Ricketts.

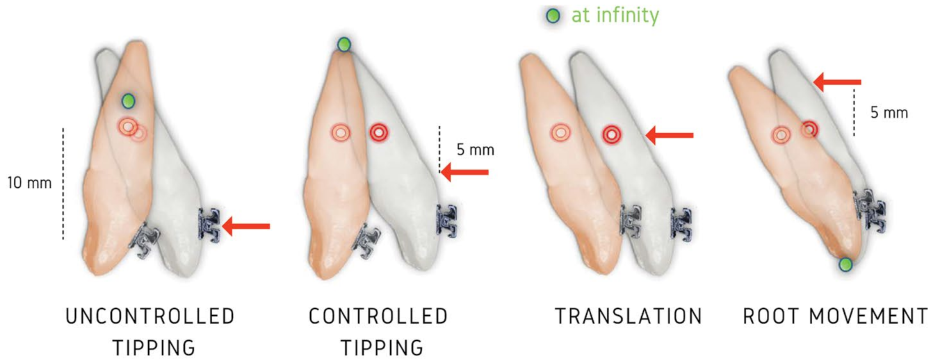


Notice that we can easily find the center of rotation at the incisal edge. In this case, again, the CRot represents a point of the tooth that did not move.

Center of rotation

THE CROTS OF THE 4 BASIC TYPES OF MOVEMENTS

Based on some classical experiments, mainly with a standard incisor, we can evaluated the position of CRot with respect to CR, either in relation to a specific M/F at the bracket or to a given M/F at the CR. These relationships can give us some general guidelines to understand how the movements differ according to these variables.



When looking at a incisor submitted to sagittal forces at different levels (in red), its movements are often clinically classified into four different types.

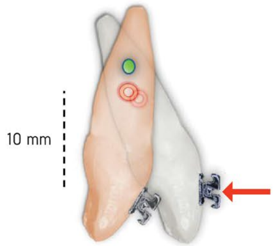
The equivalent force systems at CR related to these movements are:

Notice that when only single forces are applied to a tooth, the M/F at the CR simply represents the moment generated by the force with respect to the CR (perpendicular distance from the CR to the line of action of the force).

Types of tooth movement

Let´s describe in more details the basic types of tooth movement. And considering that you are now more familiar with the concept of equivalent systems, take this opportunity to transfer the force system at CR (in green) to an equivalent one at the bracket (in red).

This exercise will greatly increase your ability to obtain controlled tooth movements in the clinical practice. After all, the orthodontist must determine what M/F to apply to the bracket in order to obtain the correct M/F ratio regarding the CR.

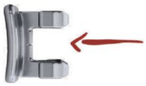


UNCONTROLLED TIPPING

If you apply a lingual force (eg. 100 g) directly to the bracket, considering that it is located 10 mm from the CR, you will notice that the crown of this tooth will be tipped to the force side while the root will move to the opposite side. The center of rotation in this case will be located just above the CR of the tooth, and this movement is called uncontrolled tipping.

M/F at CR=10

By transfering this force system (in red) to the CR, we have a M/F at CR = 10 mm.



M/F at bracket=0

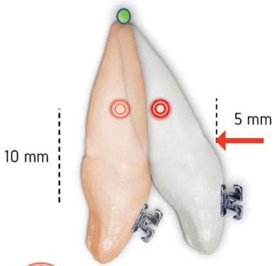
The equivalent force system at the bracket in this case has obviously a M/F=0 (the M at the bracket is zero because the force is passing directly through it).

In this case, M/F ratio at the bracket simply denotes how many millimeters away from the bracket an equivalent force could be placed.

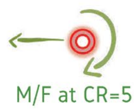
Types of tooth movement

The CONTROLLED TIPPING and ROOT MOVEMENT represent the two extremes among the 4 basic types of tooth movements.

In order to get a controlled tipping of a standard incisor (Figure A), a force is applied 5 mm below the CR. Notice that the tooth tips toward the force direction, and no part of the tooth moves in the opposite direction. That is, the center of rotation is located at the root apex.



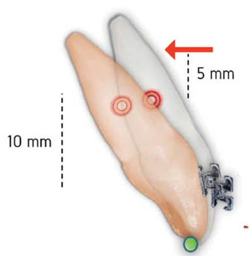
A CONTROLLED TIPPING



By transfering the force system (in red) to the CR, we have a M/F at CR = 5 mm.

The equivalent force system at the bracket in this case has also a M/F=5 mm.

In the case of a root movement (Figure B), the force passes 5 mm above the CR and the center of rotation will be located at the incisal edge.



B ROOT MOVEMENT

By transfering the force system (in red) to the CR, we have a M/F at CR = 5 mm, with the resultant moment in counterclockwise direction.

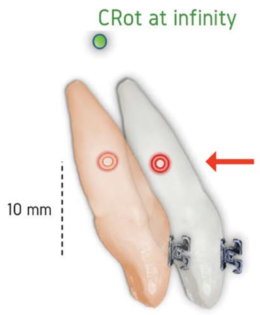
The equivalent force system at the bracket in this case has a M/F=15 mm.

In these cases, M/F ratio at the bracket simply denotes how many millimeters away from the bracket an equivalent force could be placed.

Types of tooth movement

The TRANSLATION or bodily movement is the one in which ALL points of the tooth move in the same direction, and the center of rotation is located at infinity.

In order to get a pure translational movement, the line of action should pass directly over the CR, which in this case is located 10 mm above the bracket level.



TRANSLATION

By transfering this force system (in red) to the CR, we have a M/F at CR = 0.

The equivalent force system at the bracket in this case has a M/F=10 mm.

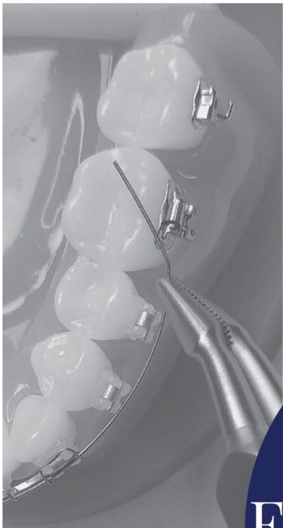
FINAL CONSIDERATIONS ABOUT TOOTH MOVEMENT PREDICTIONS

The classification presented here does not include all possible movements, after all any intermediate movement between the presented ones can be obtained.

In fact, most orthodontic movements are a combination of translational and rotational movements. That is, derived movements may result from various combinations of the translation and rotation components.

The values presented here do not represent a universal law, as the distance between the CR and the bracket is not always the same. Several factors must be considered when choosing an appropriate force system, such as root anatomy, marginal bone level and force directions.

Click HERE to see a video about the main types of orthodontic tooth movements.



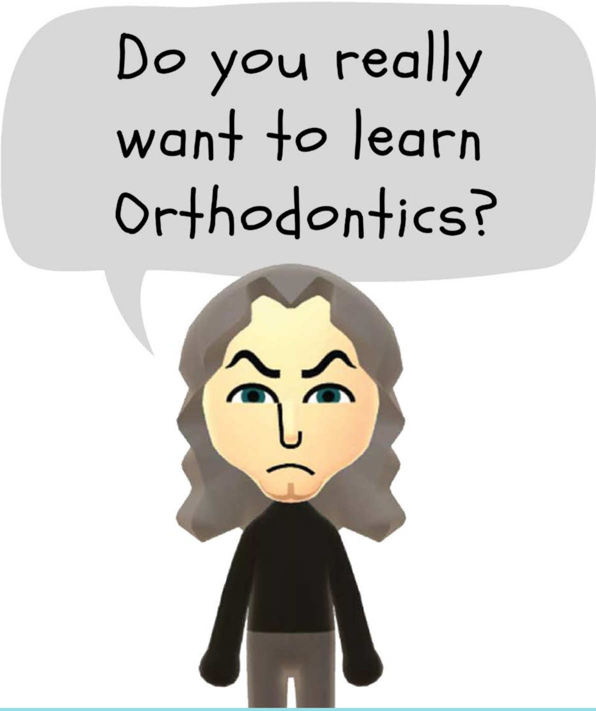
Fundament VII

VII- Every appliance must be in static equilibrium when it is installed.

The Newton´s laws

Orthodontics is probably the specialty that most depends on basic concepts and principles of physics. However, many of these principles are ignored or misunderstood by those who consistently practice the same fundamental act in their clinical routine: applying FORCES to move teeth.

Every dentist interested in moving teeth can not underestimate the incomparable contribution of Newton's laws to the clinical practice. In the next parts of this book, we will introduce and clarify the Newton's laws applied to orthodontics, with emphasis on the first law.

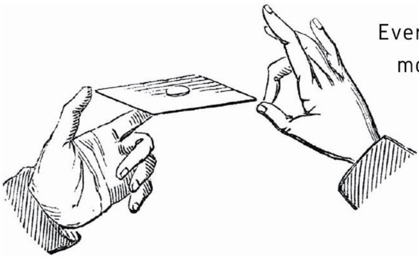


Click HERE to see the whiteboard animation "Why to study biomechanics?"

The Newton´s laws

The most fundamental basis for the understanding of biomechanics was presented in 1686 by Sir. Isaac Newton in his Philosophae Naturalis Mathematica. He presented three principles as follows:

1) LAW OF INERTIA



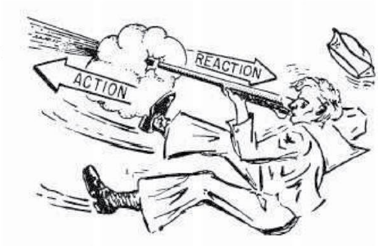
Every object continues in its state of rest or uniform motion in a straight line, unless it is compelled to change by forces impressed on it.

2) LAW OF ACCELERATION

The change of motion is proportional to the motive force impressed and is made in the direction of the straight line in which that force is impressed.

3) LAW OF ACTION AND REACTION

To every action there is always opposing and equal reaction.



Drawings: G. P. Quackenbos A.M. A Natural Philosophy: Embracing the Most Recent Discoveries in the Various Branches of Physics, and Exhibiting the Application of Scientific Principles in Every-day Life (New York: D. Appleton and Company, 1870)

The Newton´s laws

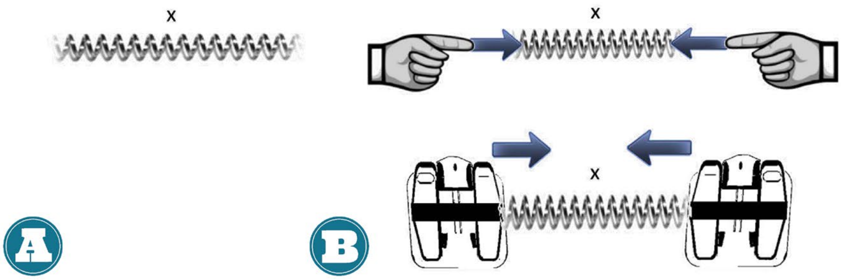
LAW OF INERTIA

In my opinion, the first Newton´s law is the most important for our clinical practice. Unfortunately, this law is often misunderstood, even in the orthodontic literature. In the next pages, we we will give detailed explanations about the application of this principle in orthodontics.

UNDERSTANDING THE PRINCIPLE OF EQUILIBRIUM:

According to the law of inertia, an object remains in a state of rest when it is not subjected to an unbalanced force. I used this term - unbalanced - because it is perfectly possible for a body to be in this state of rest, called STATIC EQUILIBRIUM, even suffering the action of forces!!

For this purpose, we only need that the forces are being counteracted by each other. An orthodontic spring compressed by equal and opposite forces (eg. placed between two teeth) represents a classic example of this equilibrium condition (Figure).

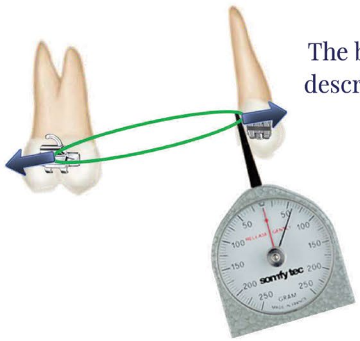


Deactivated open spring (A). When applying two equal and opposite forces on the spring, the spring will change its shape by elastic deformation, but it will not accelerate (B). Note the lack of movement in relation to a fixed reference point (x). The spring is in EQUILIBRIUM on both situations – A and B.

It's hard to imagine how an appliance at rest can exert forces to move teeth, but the fact is that ALL appliances attached between teeth will be at rest - in static equilibrium, just as the spring of our example.

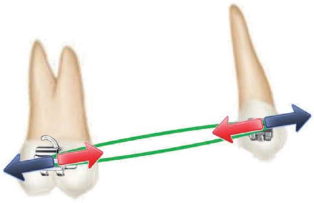
UNDERSTANDING THE PRINCIPLE OF EQUILIBRIUM:

Another simple example of this principle is an elastic stretched between two teeth. When it is installed, the elastic will not move to the right, nor to the left, nor up, nor down. That is, the appliance (in this case the elastic) will be in equilibrium! We can easily visualize the forces that hold it in this condition: they are the equal and opposite forces that the brackets exert on the elastic (blue arrows).



The blue arrows represents the ACTIVATION FORCES, described as the forces needed to activate (or install) an appliance.

WHAT ABOUT THE FORCES RESPONSIBLE FOR TOOTH MOVEMENT?



Notice that the brackets exert the ACTION forces on the elastic, and the elastic, in turn, react with equal and opposing forces, which are the REACTION forces exerted on the brackets.

The forces perceived by the teeth are called DEACTIVATION forces, and they are the ones that interest the professional, because they will be the main determinants of the direction of tooth movement.

"The wire must be in equilibrium, once it is placed between two attachments. If it were not, the wire would accelerate the patient out of the orthodontist's office." - Burstone & Koening

Fundament VIII

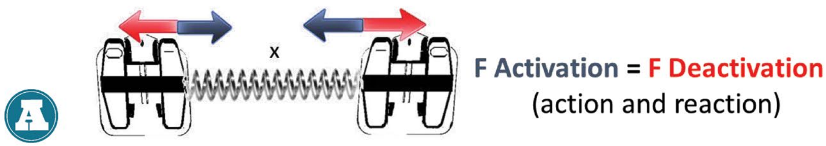
VIII- Every activation action generates a deactivation reaction.

The Newton´s laws

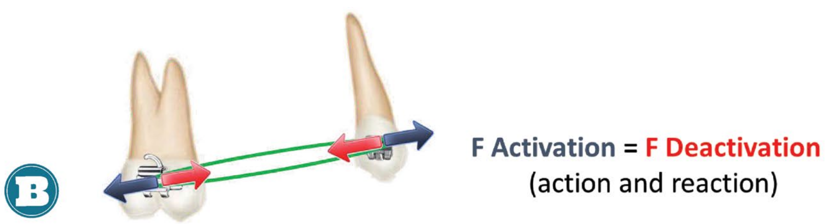
LAW OF ACTION AND REACTION

"To every action there is always opposing and equal reaction". Unfortunately, the Newton's third law is also commonly addressed incorrectly in the orthodontic literature. However, its application in orthodontics is quite simple, as explained in the following paragraphs:

Coming back to the example of the open spring inserted between two teeth (Figure A), we can see that the brackets exert the ACTION forces on the spring, and the spring, in turn, react with equal and opposing forces, which are the REACTION forces exerted on the brackets.



The determination of the deactivation forces is an extremely simple process and does not require any formula or mathematical calculation. If we know the activation forces, we simply revert the sense of the activation forces in order to obtain the deactivation forces. This is the law of action and reaction. It can be easily verified in the preceding examples of the spring (Figure A) and in the elastic (Figure B).

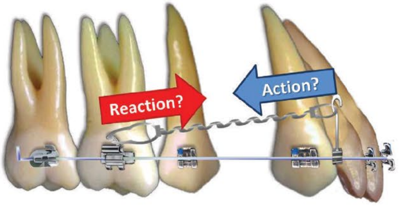


Click HERE to se a whiteboard animation about the Newton´s laws.

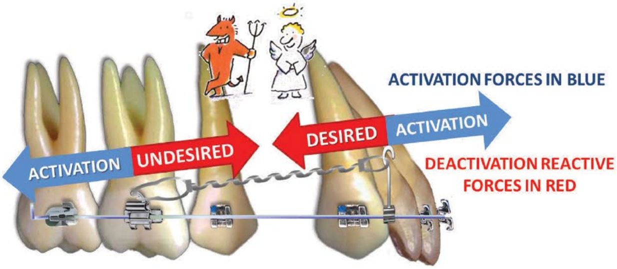
DO NOT CONFUSE THE PRINCIPLE OF EQUILIBRIUM WITH THE LAW OF ACTION AND REACTION:

Many specialists are wrong in trying to understand and explain the law of action and reaction in orthodontics. Some of them refer to Newton's third law in order to understand anchorage questions.

For example, if you consider a simple anterior retraction, in which the orthodontist wishes to retract the anterior teeth without mesial movement of the posterior teeth (the so-called loss of anchorage). Many professionals refer to the force applied to the incisors as an action force, while the posterior teeth would receive the reaction forces.



In fact, this interpretation is incorrect. It is not the Newton's third law that supports this statement. In this case, we should use the term DESIRED to describe the force on the incisors, and the term UNDESIRED to describe the force on the molars. The two are equal and opposite, but they DO NOT represent the forces of action and reaction described by Newton.



The INTERACTION between action and reaction when we insert an appliance between two teeth (or two blocks of teeth, as in the example) does NOT occur directly between the two teeth, but between the APPLIANCE and EACH of the teeth, as explained above.

The Newton´s laws

LAW OF ACCELERATION

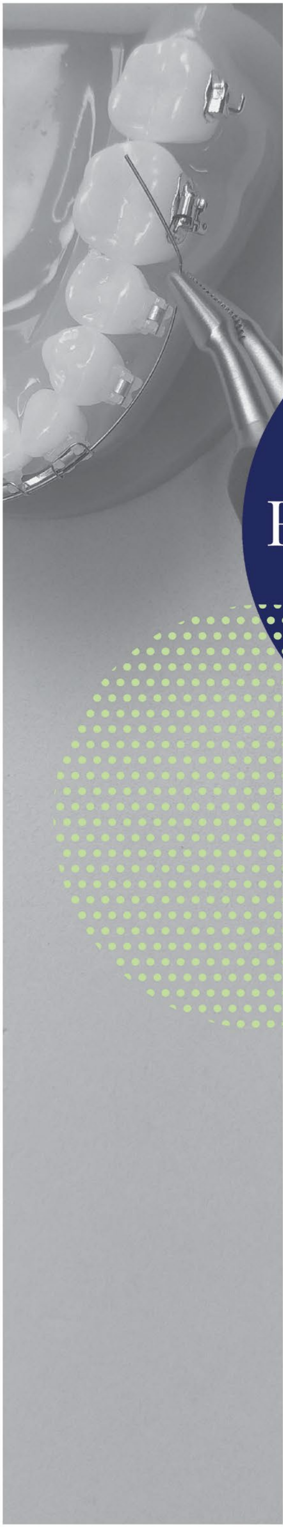
This law states that the change of motion is proportional to the motive force impressed and is made in the direction of the straight line in which that force is impressed.

You may have noticed that we did not approach in details the second law of Newton. This is because the tooth displacements during the orthodontic movement depend on complex biological responses which take days to occur, and they cannot be accurately predicted by any formula of physics (at the current state of knowledge).

At the moment we apply a force to the teeth, they suffer a minimum acceleration due to elastic deformation of the periodontal ligament, but the restriction induced by the ligament quickly places the teeth in rest position - YES, the teeth will also be in equilibrium (the force systems are counterbalanced by the forces of the ligament)!

This does not mean that the teeth will not move. Remember that different strains on ligament will trigger specific biological responses (eg. bone modeling and remodeling), and these responses will allow the tooth movement.

Although the biological aspects of tooth movement is beyond the scope of this ebook, you can watch a videolecture about the basics of bone biology HERE.



Fundament IX

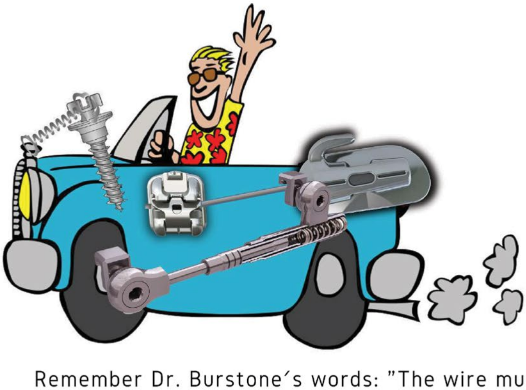
IX- Draw a free-body diagram to assess the feasibility of your force system.

How to evaluate the equilibrium of orthodontic appliances

YOUR CLINICAL LIFE DEPENDS ON THIS PRINCIPLE

In the previous pages, we explained the Newton's laws applied to orthodontics, with emphasis on the first law, THE LAW OF INERTIA, which ensures that ALL orthodontic appliances are in STATIC EQUILIBRIUM when installed.

But do you know exactly what it means to be in equilibrium? Do you know how to assess and recognize this condition? And do you comprehend the clinical applications of this knowledge?

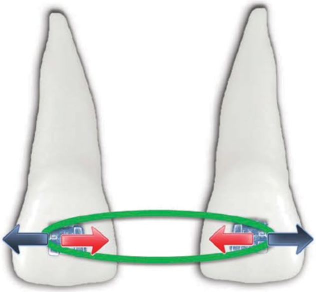


Remember Dr. Burstone´s words: "The wire must be in equilibrium, once it is placed between two attachments. If it were not, the wire would accelerate the patient out of the orthodontist's office"!!

How to evaluate the equilibrium of orthodontic appliances

WHAT IT MEANS TO BE IN EQUILIBRIUM?

Being in static equilibrium means not moving, or more specifically, not accelerating. If you install a spring, or elastic, or any other device capable of generating force, certainly this device will not suffer acceleration. The forces generated by the appliances originate from the elastic deformation of its components, which tend to return to their original shape after their interatomic bonds have changed. This elastic deformation, however, does not represent an acceleration.



When installing an elastic stretched between two teeth, for example, the appliance (in this case the elastic) will be in equilibrium. We can easily visualize the forces that hold it in this condition: they are the equal and opposite forces that the brackets exert on the elastic.

The activation forces - in blue - constitute the ACTIVATION FORCE DIAGRAM, which is a real equilibrium diagram. This force system will trigger forces of reaction (or deactivation) responsible for tooth movement.

In order to visualize the forces perceived by the teeth, simply reverse the directions of the forces in blue. We will then have, in red color, the reaction or deactivation forces, which will be perceived by the teeth.

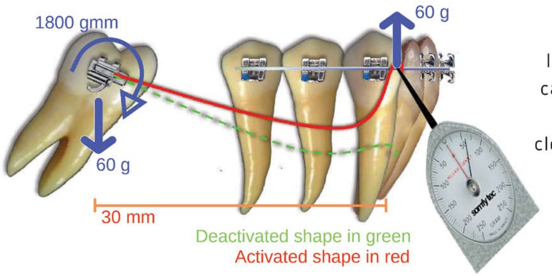
The deactivation forces - in red - constitute the DEACTIVATION FORCE DIAGRAM, which constitutes a FREE-BODY DIAGRAM.

Although all forces and moments sum to zero in a deactivation diagram, conceptually it is not an equilibrium diagram (the activation diagram is). However, considering that the deactivation diagram is originated from the activation one, all free-body diagrams acting on teeth must attend the principle of equilibrium.

How to evaluate the equilibrium of orthodontic appliances

UNDERSTANDING A FREE-BODY DIAGRAM

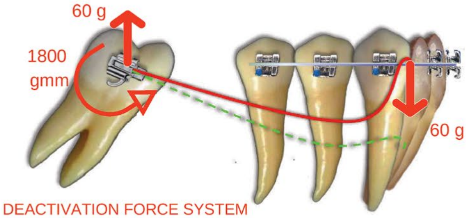
In orthodontics, a free-body diagram is a diagram showing all forces acting in a specific scenario. For example, let´s consider a cantilever whose end is inserted into a molar tube and the other end is tied to a rigid wire connecting a group of teeth (forming only one point of contact at this unit).



If you need a 60g extrusive force to attach the cantilever in the anterior unit, an intrusive force with the same magnitude combined with a clockwise couple will necessarily be applied by the molar tube (activation force system, in blue).

WHERE IS THE EQUILIBRIUM? Note that the vertical forces at the ends of the cantilever generate a counterclockwise couple of 1800 gmm. This couple is counterbalanced by the presence of the couple that exists inside the molar tube (curved arrow). So, the equilibrium of the activation forces is correct (sum of forces and moments acting on the wire is equal to zero).

REVERSE THE FORCE SYSTEMS TO GET THE FREE-BODY DIAGRAM ACTING ON THE TEETH



FREE-BODY DIAGRAMS illustrate the forces and moments perceived by both the active and reactive units.

CLINICAL TIP FOR INTERPRETING DIAGRAMS: Forces can be drawn in relation to the wire, to the bracket or to the CR of the teeth or group of teeth.

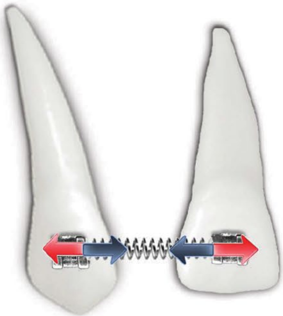
The example constitutes a statically determinate system, in which we can predict the forces and moments by the simple use of a force gauge and the principle of equilibrium.

Click HERE to see a video about this type of system.

How to evaluate the equilibrium of orthodontic appliances

VERIFYING THE EQUILIBRIUM CONDITION

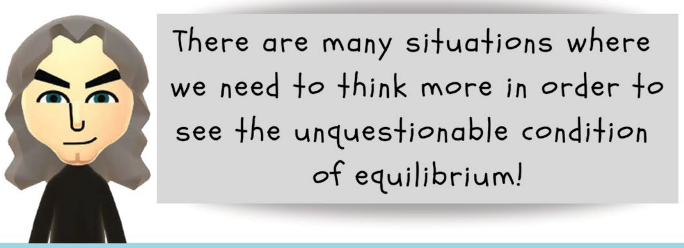
Initially, I would like to emphasize that the equilibrium condition is not an option in orthodontics. It is a principle, a law. There are no exceptions. That is, we orthodontists do not have to worry about creating a condition of equilibrium. After all, it already exists. We just need to know how to visualize and recognize this condition.



Sometimes it is very simple to verify the equilibrium of an appliance. For example, when installing a spring between two teeth, we can easily visualize the forces that hold it in this condition: they are the equal and opposite forces that the brackets exert on the spring (blue arrows). We immediately ascertain the equilibrium because the two opposing and collinear forces (that is, with coincident lines of action,) cancel out each other without producing any tendency of rotation in the appliance.

Remember that the prediction of resultant movement of teeth, however, will depend on the reaction forces (or deactivation ones, in red), which can be easily visualized by simply reversing the direction of the activation forces.

The question is that the appliances are not always as simple as the example of a single spring...

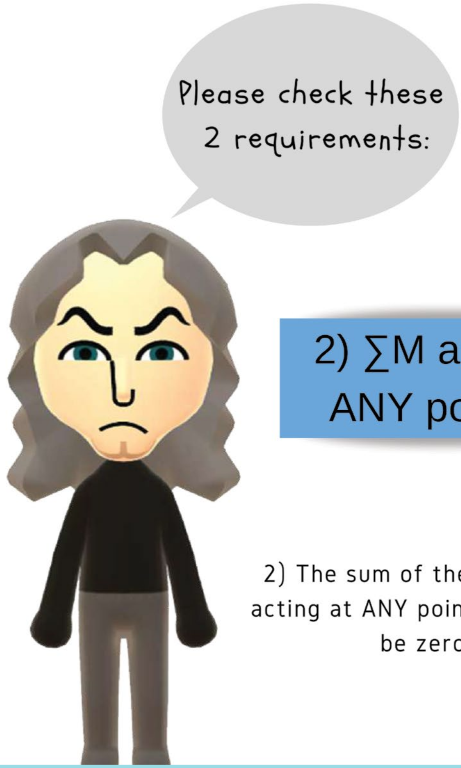


The transformation of the activation forces into reaction does not require any specific formula or reasoning: you only need to reverse the activation forces.

How to evaluate the equilibrium of orthodontic appliances

VERIFYING THE EQUILIBRIUM CONDITION

To verify the equilibrium of any appliance, we only need to RECOGNIZE the force systems involved in each particular situation. That is, we should be able to visualize the forces and moments necessary to establish the state of equilibrium. In this state, TWO requirements must be met:



1) $\sum F=0$

2) $\sum M$ around ANY point=0

1) The sum of all the forces (vertical and/or horizontal) present must be zero.

2) The sum of the moments acting at ANY point must also be zero.

VERIFYING THE EQUILIBRIUM CONDITION

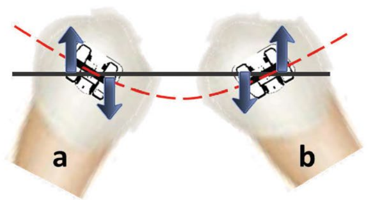
The equilibrium analysis is very useful in situations where we apply vertical and/or non-collinear forces in a system, because in these cases there are rotational forces that are not always easily visualized.

To facilitate your study, in the next pages we will explain 4 different situations, which may occur between the infinite possibilities of misalignment between two teeth. In our examples, we will use 2 angulated premolars.

VERIFYING THE EQUILIBRIUM CONDITION

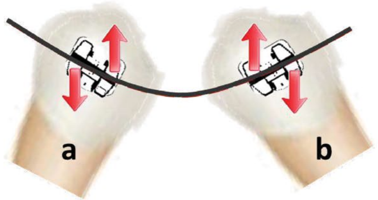
SITUATION 1:

Two teeth are rotated in opposite directions, but in the same proportion relative to the interbracket axis. To insert a straight wire between these brackets, you will need to apply two equal and opposite moments to elastically deform the wire. These moments (of activation) represent the actions of the brackets on the wire, and are obviously in equilibrium, as stated in Newton's first law.



Deactivated wire, in black
Activated wire, in red

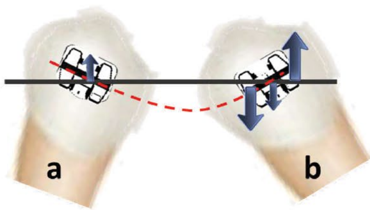
If you want to visualize the forces perceived by the teeth, simply reverse the directions of the forces in blue. We will then have, in red color, the reaction or deactivation forces, which will be perceived by the teeth.



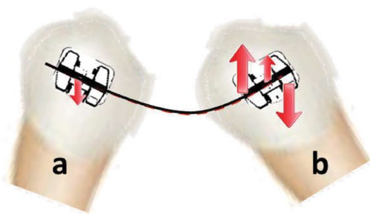
VERIFYING THE EQUILIBRIUM CONDITION

SITUATION 2:

Now, two teeth are rotated in opposite directions, one being rotated to half the quantity of the other, in relation to the interbracket axis. In this case, given the equilibrium principle, the forces and moments required to insert a straight wire in these brackets consist of an counterclockwise moment and an intrusive force at the end of the wire on the side of the tooth B, while only one extrusive force is applied to the end of the wire on the side of the tooth A.



Note that the moment of side B (counterclockwise) will be counterbalanced by the moment generated by the two forces acting on the ends of the wire. That is, the couple produced by the vertical forces in A and B is clockwise, and thus neutralizes the moment of side B. Remember the second requirement of equilibrium: the sum of the moments at ANY point in the system must be zero. If you choose a point (on tooth A, tooth B, or any other point on the wire) to calculate these values, you will verify this requirement*.



As always, after verifying the equilibrium of the activation diagram, you only need to invert the direction of the forces and moments in order to see the deactivation forces, that is, those that will be perceived by the teeth A and B.

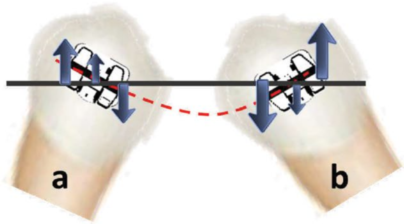
*For practical learning purposes, we suggest that you do not worry about values at this time. Just train your "clinical eye" to visualize the equilibrium of the system.

VERIFYING THE EQUILIBRIUM CONDITION

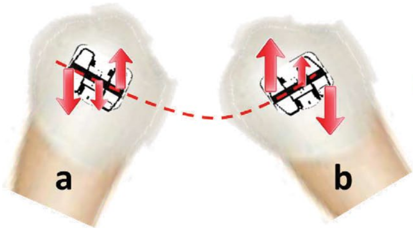
SITUATION 3:

Situation 3 exemplifies a case in which you need to perform opposite moments to insert a wire between two brackets. Considering that one moment is greater than the other, there must certainly be vertical forces at the ends of the wire for the principle of equilibrium to be met. This situation occurs, for example, if two teeth are rotated in opposite directions, one being rotated three quarters the quantity of the other in relation to the interbracket axis.

Notice again how the equilibrium has been reached: the greatest counterclockwise moment of the side B was counterbalanced by the smallest moment of the side A PLUS the moment generated by the vertical forces of the extremities (these forces form a clockwise couple).



In this case, three couples are required for equilibrium. Two couples in opposite directions and different magnitudes acting at the ends, plus one couple along the wire keeps the system in equilibrium (activation forces, in blue).

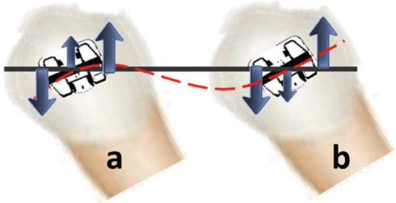


Deactivation/reaction forces, in red, that will be perceived by the teeth.

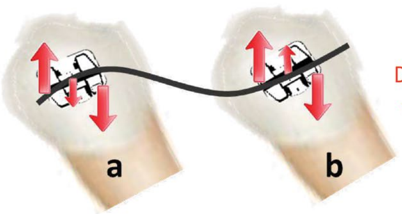
VERIFYING THE EQUILIBRIUM CONDITION

SITUATION 4:

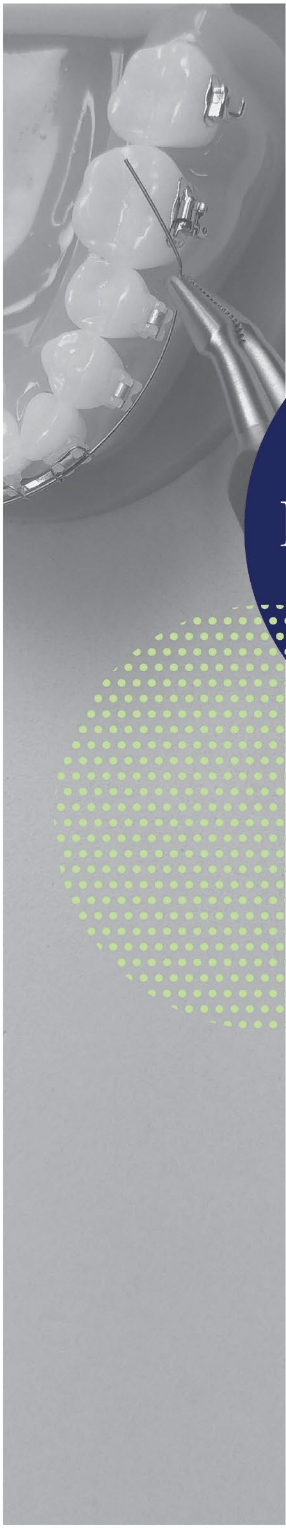
Finally, we exemplify a situation in which two equal moments in the same direction are needed to insert a wire between two brackets. This occurs, for example, when the two teeth are rotated in the same direction, and in the same proportion with respect to the interbracket axis.



In this case, the equilibrium has been reached since the moments at each end (the two counterclockwise) will be counterbalanced by the moment acting along the length of the wire (ie. the clockwise couple generated by the vertical forces in the ends of the wire) - activation forces, in blue.



Deactivation/reaction forces, in red, that will be perceived by the teeth.



Fundament X

X- Never underestimate the influence of the exact laws of physics in your clinical practice.

Equilibrium in clinical practice

HOW TO APPLY THIS KNOWLEDGE CLINICALLY?

The answer to this question requires a more in-depth study of the subject, but the understanding of the principle of equilibrium represents one of the first steps for the rational and effective application of biomechanical principles in orthodontic clinic.

The beginner may even classify this knowledge as too theoretical and complex, though it forms the basis for understanding how the appliances work. Applying the theory of equilibrium in the day-to-day clinical practice will bring innumerable positive surprises to the professional:

- You will be able to simulate and predict the desired dental movements in order to select and build the appliances with more consistent force systems.
- You will notice that sometimes some movements are scientifically impossible to realize with just one device or activation, because we will never be able to disrespect the laws of physics (eg. create an appliance that is not in equilibrium).
- In addition, you will be able to assess the actual needs of anchorage control in order to minimize undesirable side effects, while potentiating the desired movements.

Equilibrium in clinical practice

THE BASIC LINE OF REASONING

Basically, this final chapter will help you to develop a line of reasoning for the choice and activation of most orthodontic appliances inserted between two teeth, or specific groups of teeth.

It is therefore a reasoning used for the application of SEGMENTED ARCH TECHNIQUES, which are those that divide the dental arch into an ACTIVE UNIT (represented by the teeth that you want to move) and a REACTIVE UNIT (represented by the anchoring teeth which we normally do not want to move). Only with the resources of these techniques we will be able to precisely define the direction of the desired and undesired forces of our orthodontic mechanics.

This biomechanical approach is called FORCE-DRIVEN ORTHODONTICS. Differently from the shape-driven orthodontics, focused on the wire´s shape, the force-driven orthodontics emphasizes principles and force systems.

Click HERE to see a whiteboard animation about shape-driven vs. force-driven appliances.

Force-driven orthodontics

STATICALLY DETERMINATE & INDETERMINATE SYSTEMS

The detailed management of the inummerable possibilities for applying controlled force systems to move teeth is beyond the scope of this e-book. However, we consider important to provide a brief overview of some important characteristics of the two types of biomechanical systems. Please see following.

1) STATICALLY DETERMINATE APPLIANCES

Appliances in which the law of equilibrium allows us to estimate all the forces and moments acting on the wires and teeth. The main example of this system is the cantilever, which will apply only one force at the end to which it is connected, while at the other end, inserted into a tube or bracket, both a force and a moment will be produced.

The planning of movements with this type of appliance is quite simple, since the use of a tensiometer and a ruler will give you all the information about the forces and moments that will be applied in the active and reactive units.

2) STATICALLY INDETERMINATE APPLIANCES

Appliances in which we can not estimate all the forces and moments involved simply by applying the equilibrium formulas. In this type of system, a wire is inserted into two or more brackets (or tubes). In this category, we can include most orthodontic appliances, such as continuous and segmented leveling arches, retraction loops, rectangular loops, root springs, transpalatal bars, and lingual arches.

The planning of movements with this type of appliance can be very complex in some cases. In this book, we will only emphasize that the principles of equilibrium and the six geometries constitute the most fundamental topics for understanding these systems*.

*In the recomended reading section, you can ckeck my favorite references for studying this subject.

Force-driven orthodontics

THE 5 STEPS OF A FORCE-DRIVEN PLANNING

This chapter will demonstrate how to elaborate a force-driven planning. You will realize that this BIOMECHANICAL PLANNING can be used whenever you need to carry out a specific and controlled movement. This type of movement is the one in which the application of specific forces is planned by YOU, according to the malocclusion that YOU want to correct.

I'm sure that this knowledge will change your way of facing orthodontics, making it easy to solve the many complex cases routinely found in your practice. These steps can be applied to solve malocclusions in the three planes of space: transversal, occlusal or sagittal. Let´s see one example in each plane, so you can practice the application of the 5 steps:

1. IDENTIFY THE PROBLEM TO BE CORRECTED
2. CHECK IF YOUR FREE-BODY DIAGRAM IS IN EQUILIBRIUM*
3. SELECT THE APPLIANCE TO SOLVE THE PROBLEM
4. ACTIVATE THE APPLIANCE TO GET THE DESIRED FORCE SYSTEM
5. EVALUATE THE POSSIBLE NEED OF REACTIVATIONS

*The free-body diagram of deactivation forces should attend the principle of equilibrium because it is based on an appliance equilibrium condition.

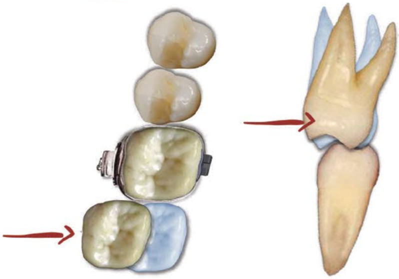
THE 5 STEPS OF A FORCE-DRIVEN PLANNING

PROBLEM 1: Second upper molar excessively inclined for the buccal side.

Chief complaint: chewing the cheek

Let´s follow the 5 steps. In this first case, an occlusal view is used for planning the movements. It is very important, however, to be aware that significant changes can also occur in other planes, depending on the case evaluated.

1 IDENTIFY THE PROBLEM TO BE CORRECTED



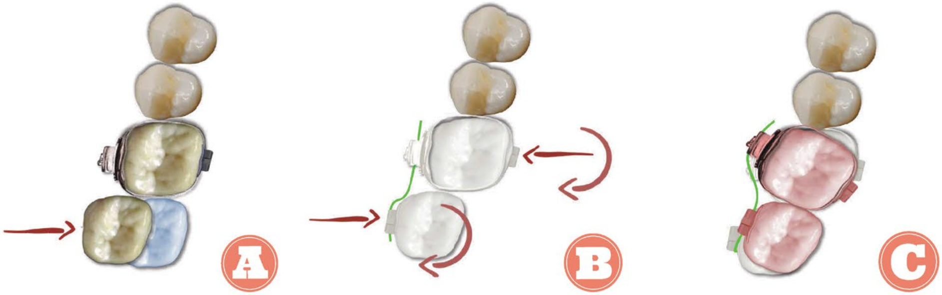
We can perceive the excessive buccal inclination of the upper second molar in both occlusal and frontal views. In this case, the simplest and most effective solution would be the application of a single lingual force in this tooth.

In this first step, different professionals usually agree about the most appropriate solution for the case. In the next steps, however, there are countless varied approaches to deal with the same problem.

THE 5 STEPS OF A FORCE-DRIVEN PLANNING

2 CHECK IF YOUR FREE-BODY DIAGRAM IS IN EQUILIBRIUM

Before taking a pen in order to draw a diagram, you may think: ”come on, this is a small problem (A), let´s bond a tube at the molars, insert a straight wire (B) and see the result (C).



The use of a straight wire in this case would not provide the force you have planned (A). The relationship between the molars creates a Class I geometry force system (B). Note the application of undesired force systems at both the first and second molars (C). This system is considered, therefore, inconsistent.
* Tooh rotations in Fig. C were exaggerated for illustration purposes.

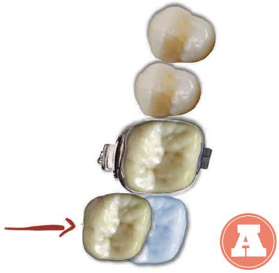
You definitely should draw a free-body diagram! You´ll be able to look for a consistent system; at the same time, possible inconsistencies can be checked, contributing for a proper anchorage selection.

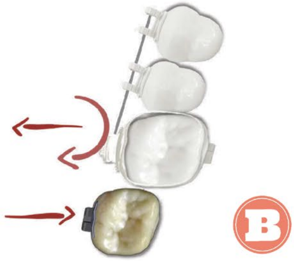
Click HERE to see a whiteboard animation about the force systems delivered by a straightwire inserted between two brackets with varying angulations (The Six Geometries).

THE 5 STEPS OF A FORCE-DRIVEN PLANNING

2 CHECK IF YOUR FREE-BODY DIAGRAM IS IN EQUILIBRIUM

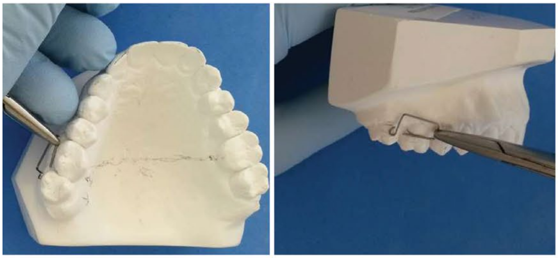
Back to our case, let´s draw a deactivation diagram based on our desired force (A). If we apply a single lingual force at the active unit, naturally a buccal deactivation force will be applied at the reactive unit. Moreover, this unit will also perceive a moment in the opposite direction of the moment related to the two previous forces (B).





The deactivation force diagram in B is compatible with your planned force (A) and is consistent regarding the active unit. This free-body diagram (B) is correct because attends the principle of equilibrium. Moreover, it demonstrates a potential side effect associated with the inconsistent force system applied at the reactive unit.

3 SELECT THE APPLIANCE TO SOLVE THE PROBLEM



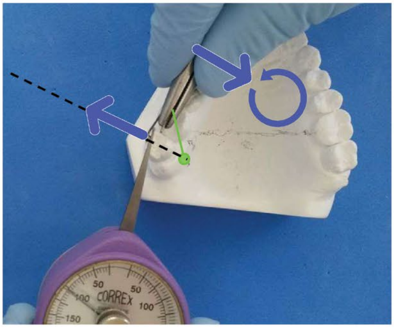
Considering that in the present case only a single force was required, a cantilever inserted into the first molar tube and ligated in some accessory (bracket, tube or buton) of the second molar was selected.

The main characteristic of this system is its high degree of qualitative constancy (M/F ratio), that is, the system maintains the directions and proportions of its forces and moments during the deactivations - this results in a more homogeneous and predictable orthodontic movement.

THE 5 STEPS OF A FORCE-DRIVEN PLANNING

4 ACTIVATE THE APPLIANCE TO GET THE DESIRED FORCE SYSTEM

There are infinite possibilities of configurations for the cantilevers. We can incorporate bends and curvatures into the cantilever in order to change the line of action of the resulting force, and thus obtain the desired force system for a specific orthodontic movement. They are usually made with titanium-molybdenum (TMA) wires.



Activation diagram in equilibrium.

Basically, the cantilever activation is made folllowing a rule of thumb: make a deactivated shape (in green) by which a line between the points of ligation (from the deactivated to the activated shape) will establish the desired line of action (black traced line).

5 EVALUATE THE POSSIBLE NEED OF REACTIVATIONS

As previously mentioned, the cantilevers present a high degree of qualitative constancy (M/F ratio), keeping the directions and proportions of its forces and moments during deactivation. In some case, as in the present one, no reactivation was needed.

Deactivation diagram and the results after a few months (only the desired tooth was moved).

Since the force and moment in the reactive unit were not desired, we used an extensive anchorage unit, composed of two posterior segments joined by a transpalatal bar.

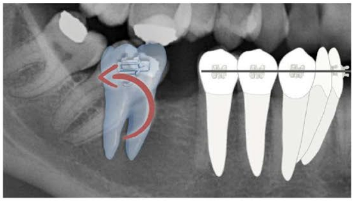
THE 5 STEPS OF A FORCE-DRIVEN PLANNING

PROBLEM 2: Second lower molars excessively angulated for the mesial side.

Chief complaint: black spaces in the mouth

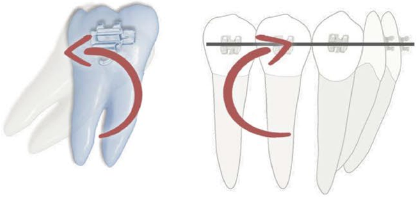
Let´s follow the 5 steps again, focusing on the process of molars uprighting, a very common situation in adult orthodontics.

1 IDENTIFY THE PROBLEM TO BE CORRECTED



Our ideal system of forces for this molar would be the application of only a counterclockwise moment. We do not want any extrusive or intrusive force on this tooth.

2 CHECK IF YOUR FREE-BODY DIAGRAM IS IN EQUILIBRIUM



This diagram was a piece of cake!

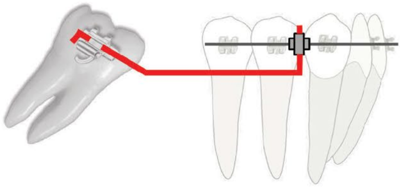
If we apply a moment in the active unit (in blue), we know, by the law of equilibrium, that a moment in the opposite direction in the anchorage unit (in grey) will be generated.

In this case, our anchorage unit will be formed by the 10 lower teeth, from premolar to premolar, conjugated with a rigid steel arch. This will minimize the undesired moment.

THE 5 STEPS OF A FORCE-DRIVEN PLANNING

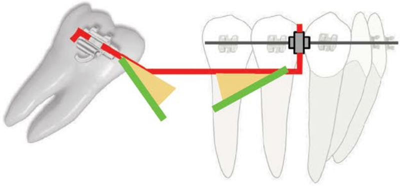
3 SELECT THE APPLIANCE TO SOLVE THE PROBLEM

Whenever you wish to exclusively apply moments by using only one appliance, this system will certainly be statically indeterminate. That is, it will be an appliance whose ends will be inserted into two teeth or group of teeth (active and reactive units).



A good choice for this case is a root spring, a segment of wire (usually TMA) which is initially made passive, with one end attached to the auxiliary tube of the molar that we want to move, and the other end fitted into a cross tube adapted between the canine and first premolar.

4 ACTIVATE THE APPLIANCE TO GET THE DESIRED FORCE SYSTEM



The root spring was activated by making two V bends near each insertion site (truncated V). The angulation of the bends (around 40 degrees each) was equal in both extremities based on the arms of the spring starting at a passive angle.

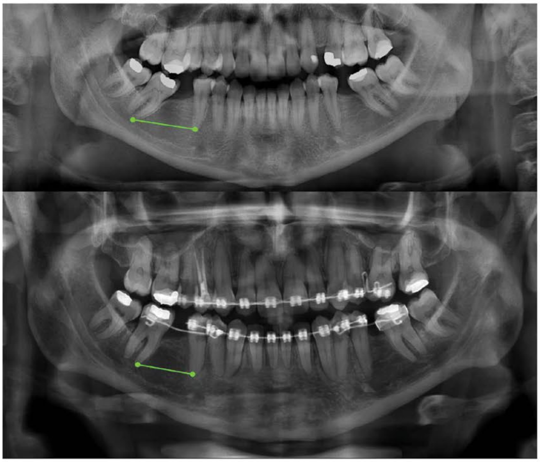
5 EVALUATE THE POSSIBLE NEED OF REACTIVATIONS

The reactivations using statically indeterminate systems are more complex and require more rigorous clinical control than the statically determinate appliances.

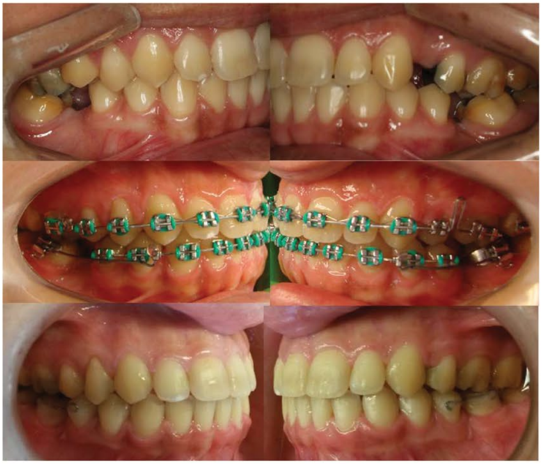
That is, when the patient returns one month after you have installed your appliance, your activation has probably changed. Yes, you can not forget that your teeth will move with your activation. In our example, imagine that your molar rotated a few degrees while the reactive unit held its position because it was anchored. In this case, the movement of the active unit has already changed the configuration of the force system. Of course! The activation was specific to the teeth positioned BEFORE moving. When dental positions change, the force systems also change!

As a practical tip, whenever you use a statically indeterminate appliance to produce equal couples (Class VI geometry force system), it is best to reactivate it monthly, because its deactivations quickly cause changes in the system of forces during tooth movement.

THE 5 STEPS OF A FORCE-DRIVEN PLANNING



In our example, root springs were installed on both sides of the patient, and the two molars were uprighted at an impressive speed, since the correct force system was applied (force-driven orthodontics!).



After the uprighting, we used a shoehorn loop to close the spaces, and since these were not very large, the control of the anterior anchorage* was made only with torque control to avoid the inclination of anterior teeth to the lingual.

*CLINICAL TIP: for mesialization of posterior teeth with greater need for anterior anchorage control, we suggest the use of a mandibular protractor (eg. Power Scope) for this purpose. Click HERE to watch a video with a simulation of this situation.

Click HERE to see a typodont simulation showing the confecction and activation of a root spring used for uprighting molars.

THE 5 STEPS OF A FORCE-DRIVEN PLANNING

PROBLEM 3: Upper left segment excessively inclined for the buccal side (scissor bite).

Chief complaint: difficult chewing on the left side

This last case is more complicated than the previous ones. Let´s follow the 5 steps again, focusing on the asymmetrical width constriction, where the left upper side requires lingual tipping. I hope you can se how the use of an appropriate system of forces can work in our favor to obtain controlled dental movements.

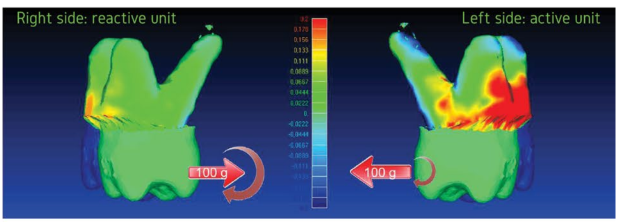
1 IDENTIFY THE PROBLEM TO BE CORRECTED

Although there are many solutions for this case, the presented approach has used a combination of contraction with third order activation (or torque) to obtain a unilateral contraction of the upper arch.

The reason for this approach has not only mechanical goals, but also biological ones. The asymmetrical movement can be achieved by the application of differential moments. That is, this concept is based on the fact that tipping movements occur much more rapidly than translational movements.

Finite element analysis showing the tooth displacements and radial strains on periodontal ligament induced by asymmetrical activation of a transpalatal arch (TPA).

The red forces represent the desired force system (this is not an equilibrium diagram).

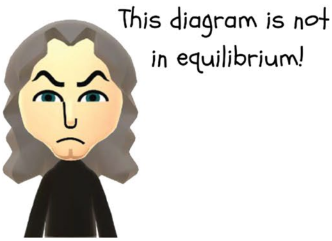


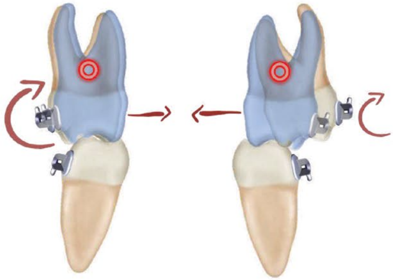
EXPLANATION: When a simple force is applied to the crown of a tooth, the stresses and strains of the periodontal ligament will be significant in some areas, which favors the action of the bone cells responsible for orthodontic movement (left side). On the other hand, if we apply the same force to a tooth, at the same time that we add a moment to obtain a translational movement, the strains values of the periodontal ligament are much lower, minimizing the cellular reactions responsible for the movement (right side).

THE FORCES AND MOMENTS IN RED REPRESENT THE PLANNED FORCE SYSTEM FOR THIS CASE.

THE 5 STEPS OF A FORCE-DRIVEN PLANNING

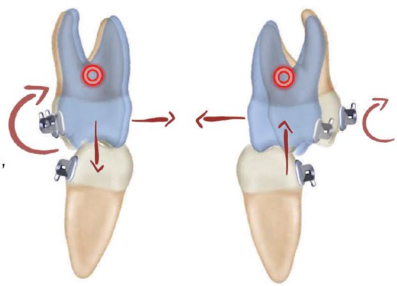
2 CHECK IF YOUR FREE-BODY DIAGRAM IS IN EQUILIBRIUM





DRAWING A CORRECT THE FREE-BODY DIAGRAM:

In order to make the desired force system feasible, undesirable (but inevitable) vertical forces will be generated with this type of activation. Now, we have a correct free-body diagram in equilibrium.



The major side effect in this case is the vertical extrusive force. Depending on the patient´s masticatory forces and facial pattern, this force can be problematic.

CLINICAL TIP: The application of occlusal splints* can reinforce the anchorage on the side we do not want to move (right side). Applying the splint on this side will also avoid the occlusal contacts on the side on which we want to make the movement. In this way, the desired movement will be optimized as it is occurring in a region free of any interference.

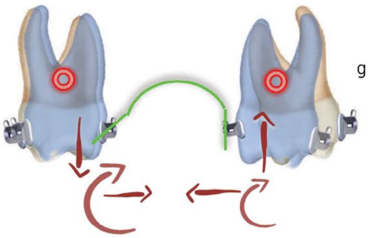
*Click HERE to see a video demonstrating an occlusal splint confecction.

THE 5 STEPS OF A FORCE-DRIVEN PLANNING

3 SELECT THE APPLIANCE TO SOLVE THE PROBLEM

The combination of contraction forces with the desired differential moments was obtained by an asymmetrically activated TPA, made with 0.032-inch stainless steel wire to reduce its load-deflection range.

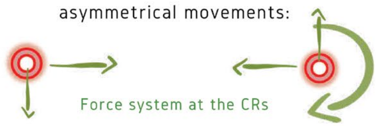
4 ACTIVATE THE APPLIANCE TO GET THE DESIRED FORCE SYSTEM



Force system at the lingual tubes

The TPA was constricted and a lingual root torque was applied only on the right side. This unilateral torque generates a system of forces similar to a Class III geometry force system (at the tubes).

The equivalent system at CR determines the resultant asymmetrical movements:



5 EVALUATE THE POSSIBLE NEED OF REACTIVATIONS

As mentioned before, a careful clinical monitoring is strongly recommended when using statically indeterminate appliances, such as the TPA. In the present case, the selected activation could keep a constant moment-to-force ratio throughout the correction of the scissor bite, since the applied force system has a large range of deactivation.
Once the scissor bite is corrected, the TPA can be either inactivated to avoid undesirable movements, or reactivated according to the needs of the case.

Click HERE to see a video with the full clinical analysis of this scissor´s bite case.

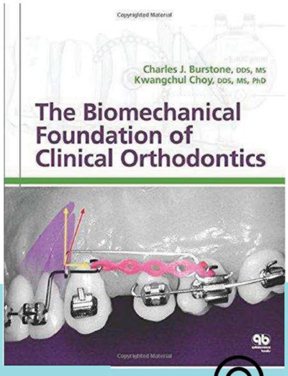
Recommended reading

"If the facts don´t fit the theory, change the facts." This provocative quote by Einstein made me think about the importance of a solid theoretical and scientific basis for practical activities, such as orthodontics. Due to its essentially practical nature, unfortunately some theoretical principles are often minimized or neglected during clinical activities.

That´s what has brought me the necessary motivation to write the present ebook. I hope it can be a useful guide for your continued process of education. Regardless of the techniques you use, I strongly suggest you dedicate your time to learning these theoretical foundations. Certainly, they will assist you in optimizing your clinical practice. The understanding of any appliance action will also be improved. After all, our specialty has been – and will always be – governed by the physical and biological laws involved in orthodontic movements.

Besides the scientific articles mentioned in this ebook, I would like to share my opinion about the most relevant textbooks in which the biomechanical foundations for clinical practice can be studied. They are:

1 The biomechanical foundation of clinical orthodontics (authors: Charles Burstone and Kwangchul Choy)



In my opinion, this book could be considered the "Bible of Orthodontic Biomechanics" for several reasons. First, it´s worth remembering that Dr. Burstone is considered the father of scientific biomechanics. Second, the organization of the chapters, the excellent illustrations and diagrams, together with detailed and appropriate scientific explanations turn this reference into a must-have book for orthodontists of all levels.

Recommended reading

2 Biomechanics in orthodontics (authors: Giorgio Fiorelli and Birte Melsen)

This e-book from the worldwide experts Dr. Fiorelli and Dr. Birte Melsen comprises a valuable tool for those interesting in going deep into the biological and mechanical concepts of orthodontic tooth movement. The book contains videos, flash animations and clinical cases illustrations about several orthodontic appliances, especially the segmented ones, used for solving complex cases.

3 Common sense mechanics in everyday orthodontics (author: Tom Mulligan)

Professor Tom Mulligan made a great job to popularize and simplify the complex topics of orthodontic biomechanics. He explained the universal principles of biomechanics with a very didactic and practical approach, focused on the application of simple bends in order to obtain appropriate force systems, by using mainly round wires, which can be used both in the mixed or permanent dentition.

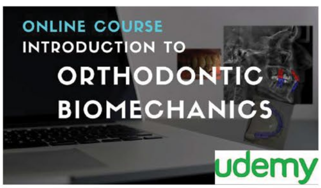
Recommended reading

I end this ebook inviting you to visit our website WWW.ESSENTIALBIOMECHANICS.COM

The mission of our blog is to contribute to the dissemination of the scientific principles on biomechanics. We have several videos about orthodontic appliances in our YOUTUBE CHANNEL, and we hope they can help you in optimizing your techniques.

For those who haven´t had the time to go deep into complex scientific articles, we also suggest our ONLINE COURSE – focused on teaching the fundamental concepts of bone biology and orthodontic mechanics*.

*The first 100 subscribers can have a 40% discount on the Online Course Introduction to Orthodontic Biomechanics and reach this knowledge with updated and truly didactic material! Plus, all participants are protected by a 100% money-back guarantee.



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