STATIC EQUILIBRIUM AND ITS IMPORTANCE

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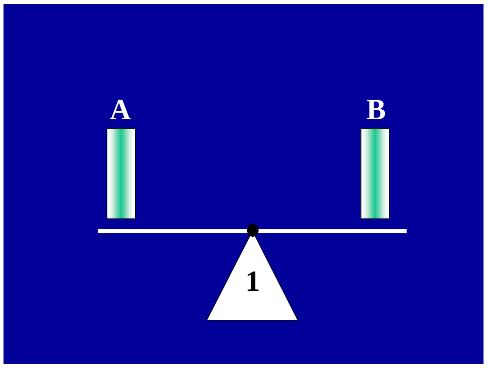


Figure 3-1

Everyone has had the experience in life of being in balance or out-of-balance. Whether balance has been lost due to excessive drinking or playing on a teeter-totter while young, the experience of imbalance at one time or another is certainly universal in nature.

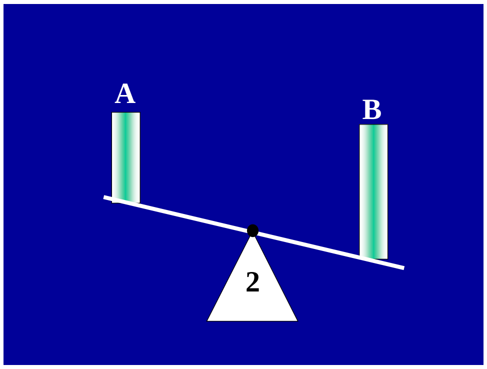


Figure 3-2

The following few illustrations will demonstrate balance and imbalance. No one will question the outcome of two individuals seated on the teeter-totter as shown in Figure 3-1. If two individuals are of equal weight and equal distance from the fulcrum in Figure 3- 1, they will be in complete balance - a state known as *static equilibrium.*

No one will question this because of personal experience. When we experience an event, we accept it as a fact. This can lead to an interest in learning the cause/effect relationships involved and provide later solutions in orthodontic biomechanics.

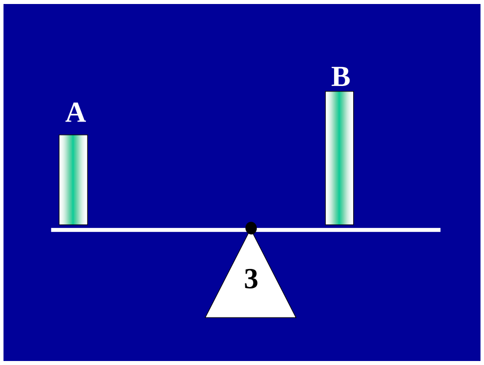


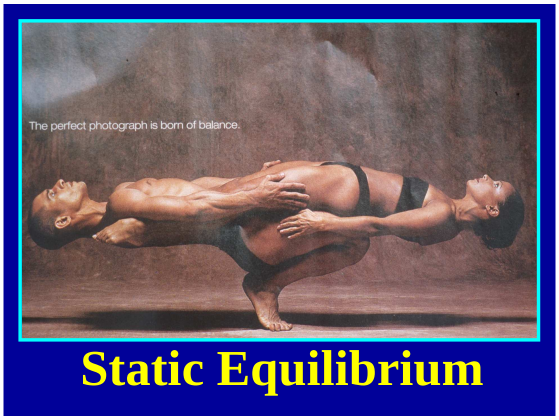
Figure 3-3

In Figure 3-2, if the same two individuals are of unequal weight and sitting at the same distance from the fulcrum, balance will only take place following displacement at which time static equilibrium will again be established. No one is going to question this outcome because it has undoubtedly been experienced in childhood.

In Figure 3-3, it is shown that the imbalance that occurred in Figure 3-2 can be restored to a state of balance if the two individuals simply shift their weight so that the larger individual is *closer* to the fulcrum than the smaller individual. Of course, the opposite is also true. The smaller individual can relocate a *greater* distance from the fulcrum. No one will question what has been demonstrated in these three illustrations as all are based on personal experience. The wonderful thing about personal experience is that the outcome cannot be questioned. Instead, the cause can be determined with an analysis.

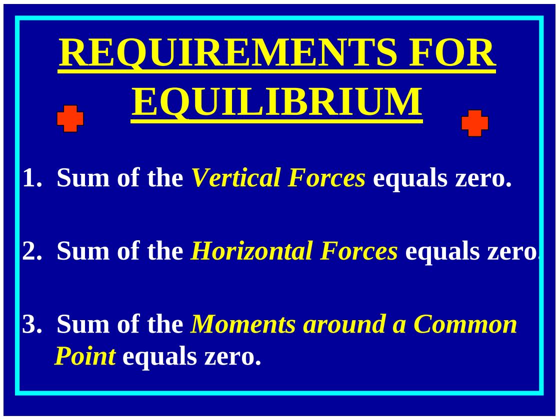
The requirements for static equilibrium take place in orthodontic treatment just as they do with the teeter-totter. Because there are no exceptions to static equilibrium when archwires are fully engaged, the orthodontist has the opportunity to determine what forces and moments are present regardless of any visual perceptions that may be very misleading and totally incorrect. Many intelligent orthodontists have come to incorrect conclusions regarding the force systems proposed for specific methods of treatment. A thorough understanding of static equilibrium will change many such conclusions.

Let’s begin by seeing why static equilibrium is established in the examples of the teeter-totter. It is important to recognize that there are three requirements for static equilibrium.



Static Equilibrium

Figure 3-4



REQUIREMENTS FOR EQUILIBRIUM

1. Sum of the *Vertical Forces* equals zero.
2. Sum of the *Horizontal Forces* equals zero.
3. Sum of the *Moments around a Common Point* equals zero.

Figure 3-5

Figure 3-4 beautifully illustrates static equilibrium whose three requirements are stated in Figure 3-5. The first requirement states that the *sum of the vertical forces must equal zero*. The second requirement states that the *sum of the horizontal forces must also equal zero*. Finally, the third requirement states the *sum of the moments measured around a common point must also equal zero.* None of these requirements may be absent in any case regarding static equilibrium.

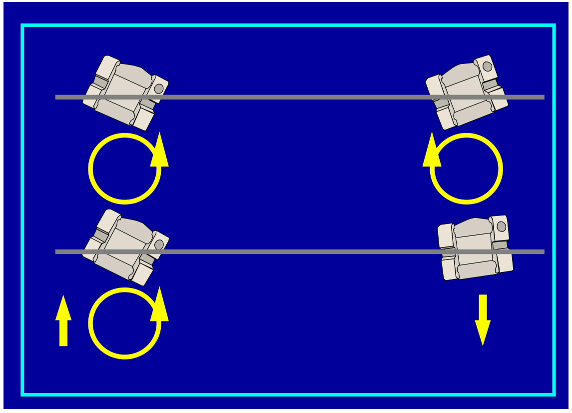


Figure 3-6

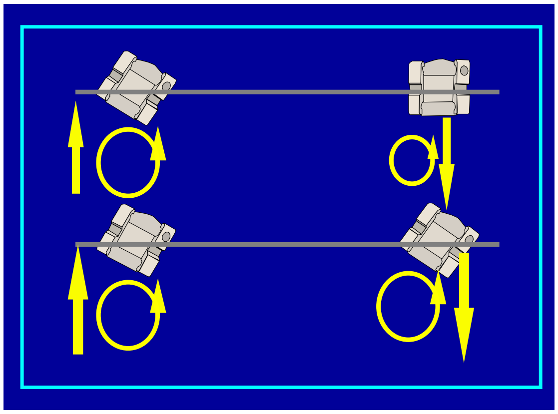


Figure 3-7

With prescription brackets so widely in use today, forces and moments are produced that must always meet these three requirements. How many orthodontists actually recognize the *total force systems* produced with various wire/bracket angles as shown in Figures 3-6 and 3-7? Since the design of prescription brackets is to replace the need to bend archwires in such a manner as to produce the desired *shape* for tooth movement, the forces and moments produced will be those that meet the requirements for static equilibrium. In other words, a specific force system *must* meet these requirements. Orthodontists often do not recognize the *total force systems* required for equilibrium and concentrate instead on those forces and moments desired for the particular type of tooth movement in question. In the Class II division 2 malocclusion, forces for overbite correction or moments for torque may be the prime considerations without recognizing that balancing forces will occur that can create as much undesirable response as the tooth movement which has been intended.

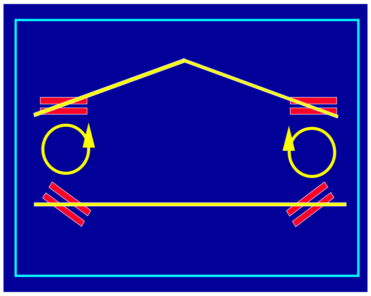


Figure 3-8

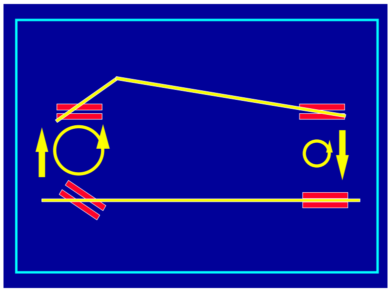


Figure 3-9

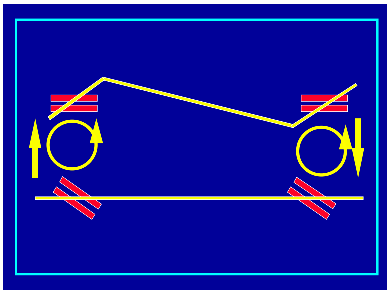


Figure 3-10

The wire/bracket angles shown in Figures 3-8 thru 3-10 will be discussed in great deal when the subject of *Wire/Bracket Relationships* is discussed. Looking closely at these illustrations, it will be noted that the wire/bracket angles are identical in both upper and lower portions of each figure. In the upper portion, the bracket slots are level with bends placed in the archwire, whereas in the lower part of each illustration, the archwires have no bends, but instead the brackets are angulated. Such angles may be purposely introduced into the appliance or may be produced by the malocclusion. In either case, a force system will be produced in order to meet the complete requirements for static equilibrium. If there is any difficulty in identifying the total force system in each of the above, then the unrecognized aspect of the force system may be the cause of undesirable responses that lead to the use of preventive measures such as lingual or transpalatal arches. Figure 3-11 tends to create controversy with those *visually oriented* in determining force systems, as it appears the smaller moment should be clockwise. Such is simply not the case. Contrary, however, to the *visual assumption*, resilience causes just the opposite. Although resilience has already been introduced as one of the factors that sometimes creates difficulty in recognizing the correct force system, a *wire/bracket analysis* will now be done to prove what the total force systems must be in order to comply with the three requirements for static equilibrium. Remember again there are no exceptions.

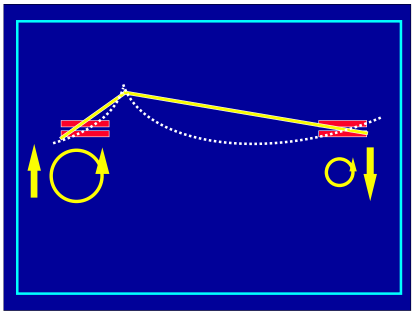
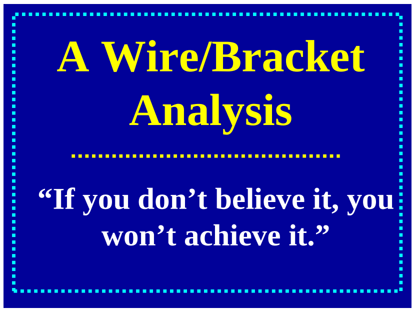


Figure 3-11



A Wire/Bracket Analysis

"If you don't believe it, you won't achieve it."

Figure 3-12

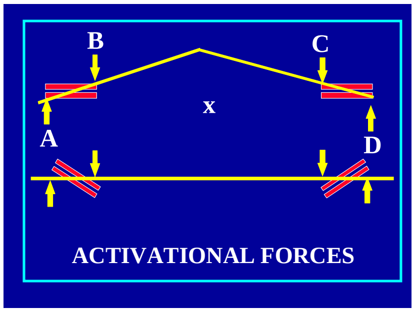
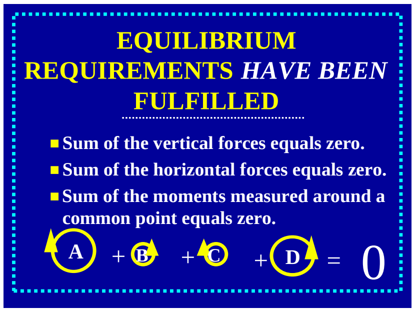


Figure 3-13



EQUILIBRIUM REQUIREMENTS *HAVE BEEN* FULFILLED

- Sum of the vertical forces equals zero.
- Sum of the horizontal forces equals zero.
- Sum of the moments measured around a common point equals zero.

Figure 3-14

In Figure 3-12, it is true that *"If you don't believe it you won't achieve it."* This analysis should eliminate any doubts regarding the forces and moments present. Only Figures 3-8 and 3-10 will be analyzed as they represent the extremes in the angles created.

Beginning with Figure 3-13, forces necessary to engage the wire into each slot are shown. These are referred to as activational forces. It is obvious that two activational forces will be required at each bracket for insertion into each slot. At this point it will be *assumed* that such forces are all equal in magnitude. This is only an *assumption* and remains to be proven as all three equilibrium requirements must be met and must be proven. If the *assumed* forces are all equal, then their sum equals zero and the first requirement for equilibrium has been fulfilled. There are no horizontal forces, so therefore the second requirement has also been fulfilled. Finally, the sum of the moments must equal zero when measured around a common point. Any point can be utilized, but for the sake of convenience a point marked X will represent the point to be used. If each force is now multiplied by the perpendicular distance to this point, it will be seen that their sum is equal to zero. Forces A & D produce equal and opposite moments and the same is true with forces B & C. Therefore, the three requirements have been fulfilled as shown in Figure 3-14.

The next step is to complete the activational force system. In Figure 3-15, the force system is determined by taking the already proven equal and opposite forces at each bracket and recognizing that these couples result in pure moments.

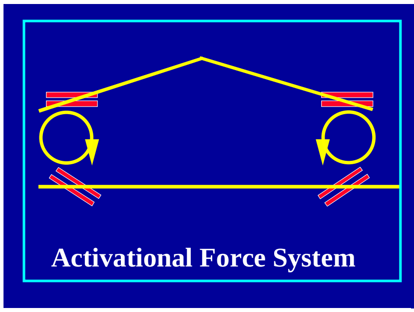


Figure 3-15

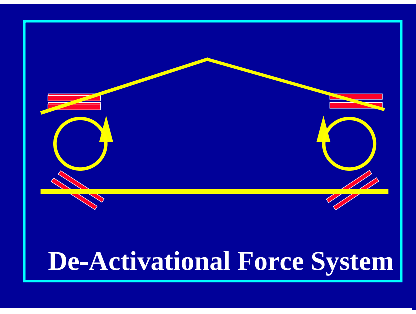


Figure 3-16

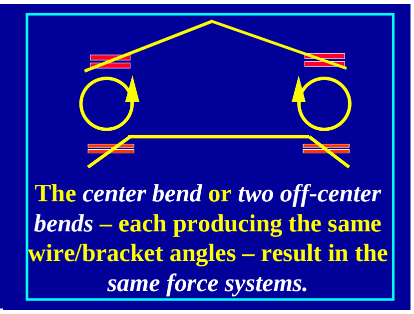

The *center bend* or *two off-center bends* – each producing the same wire/bracket angles – result in the *same force systems.*

Figure 3-17

The deactivational force system in Figure 3-16 is simply a reversal of the activational force system. Finally, in Figure 3-17, it is shown that a bend in the center is exactly the same as two *off-center bends* whenever the angles are equal and opposite. This is a significant relationship which will be utilized in effective clinical treatment at a later point.

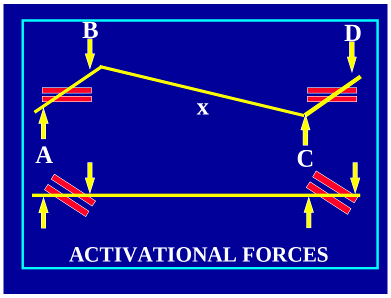
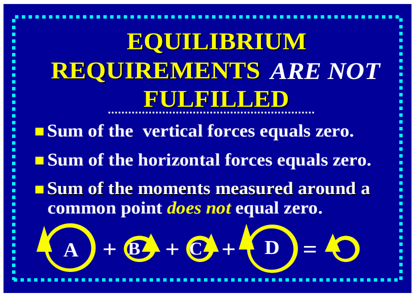


Figure 3-18


EQUILIBRIUM REQUIREMENTS *ARE NOT* FULFILLED

- Sum of the vertical forces equals zero.
- Sum of the horizontal forces equals zero.
- Sum of the moments measured around a common point *does not* equal zero.

Figure 3-19

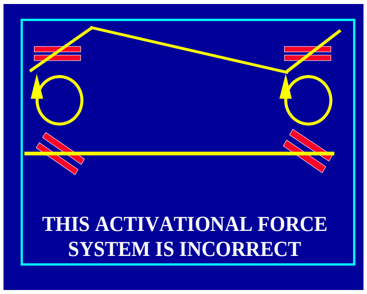


Figure 3-20

Figure 3-10, shown earlier, will now be analyzed. Looking at Figure 3-18, an *assumption* has again been made that the activational forces are equal and opposite. Thus, the first two requirements for equilibrium again are met. When summing the moments around a common point as was done before, it can be seen in Figure 3-19 that the third requirement has not been met, as Figure 3-20 shows a net clockwise moment. Therefore, our original assumption of equal and opposite forces cannot be correct. This force system is completely unbalanced, as a couple is required on the system in order to provide a balancing moment in the opposite direction of the net moment shown. When the first system was analyzed and the center bend found to produce equal and opposite moments, one moment balanced the other and therefore no forces were required. In this case it can be seen that the net system consists of a clockwise moment. It will be seen with a continued analysis that such balancing forces will be proven to exist. In Figure 3-21, it will now be *assumed* the forces acting at each bracket are unequal. We are seeking proof that equilibrium requirements are met.

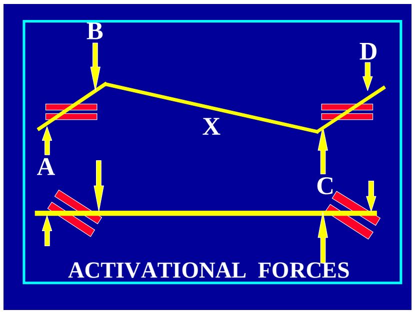
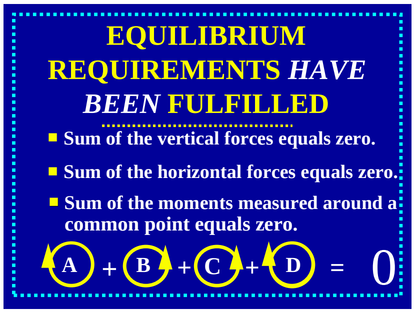


Figure 3-21



EQUILIBRIUM REQUIREMENTS *HAVE BEEN* FULFILLED

- Sum of the vertical forces equals zero.
- Sum of the horizontal forces equals zero.
- Sum of the moments measured around a common point equals zero.

A + B + C + D = 0

Figure 3-22

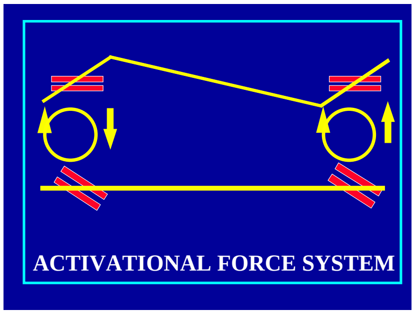


Figure 3-23

Although the forces are unequal, when all the forces on the system are added, the total forces in the vertical plane of space again equal zero, so the first requirement is fulfilled. Likewise, the second requirement is again fulfilled because there are no horizontal forces present. The third requirement is now met as each force, multiplied by the distance to the common point X, when added now equals zero as shown in Figure 3-22. Therefore, the correct activational force system in Figure 3-23 has been proven and now is reversed as shown in Figure 3-24 to show the deactivational force system. The deactivational force system is of interest to the orthodontist as it represents tooth movement.

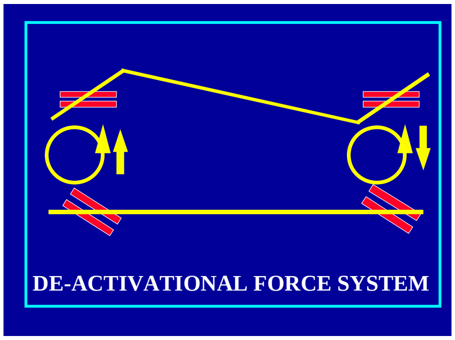
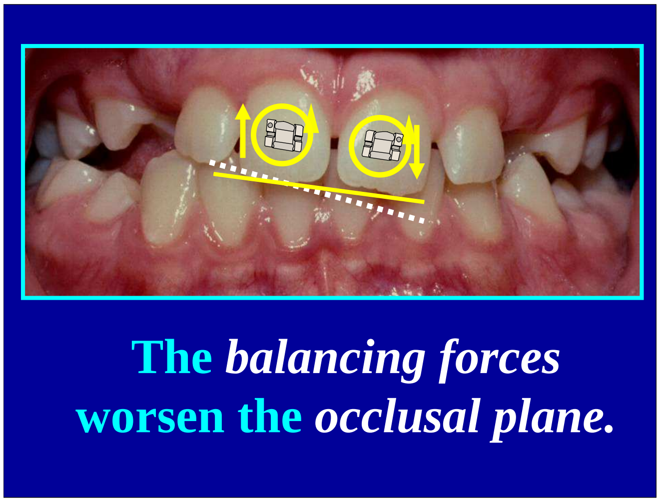


Figure 3-24

Now that a wire/bracket analysis has been demonstrated to prove force systems that meet the three requirements of equilibrium, a discussion can take place regarding the force acting at each bracket whenever a net moment is present on the system. Such forces are equal and opposite and constitute a couple. Why must such forces be present? Remember that equal and opposite forces - known as a *couple* - produce a pure moment. Therefore, the presence of a couple in any force system producing net moments at the brackets simply results in a balancing moment. The balancing moment is opposite in direction to the net moment produced at the brackets.



The *balancing forces* worsen the *occlusal plane.*

Figure 3-25

In the following clinical examples, the couple that is required in order to produce balancing moments will be shown. In Figure 3-25, there are counterclockwise moments shown for the correction of an apical base discrepancy which result in a worsening of the midline. Because this would result in an unbalanced system. a couple is automatically introduced as it provides a pure moment in the opposite direction which is equal and opposite to the moments placed by the orthodontist. The canted occlusal plane worsens.

If looking only at the individual force acting at each of the incisor brackets, it can be seen that the two forces result in a clockwise moment. No measuring is involved as this balancing moment is equal and opposite to net moments intentionally placed at the brackets by the orthodontist. Equilibrium is something to be respected, as the failure to recognize the complete force system can result in unexpected consequences that may result in an increase in treatment time for the patient - not to mention frustration for the orthodontist.

Not only will further balancing forces be demonstrated, but it will also be shown that different types of tooth movement may actually require the same force systems – not different force systems as one might expect.

In Figure 3-26, two tooth-moving systems are illustrated. A partial appliance is shown with a tip-back bend which on activation will produce an intrusive force for overbite correction while another partial appliance is shown with a wire containing twist for lingual root torque when activated.

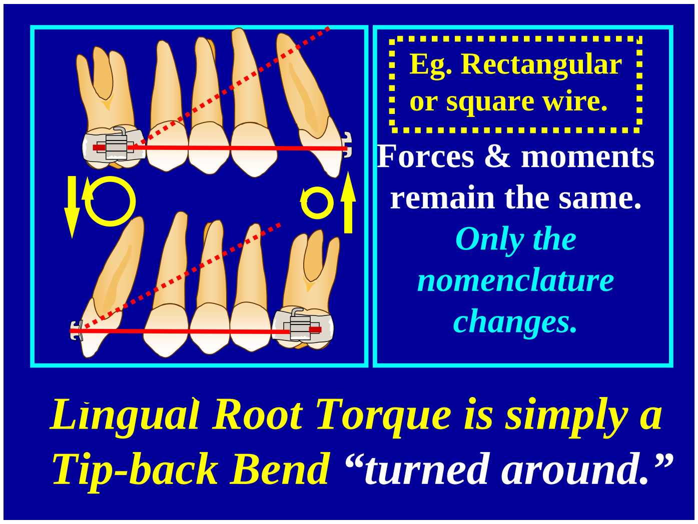


Figure 3-26

Although the objectives differ, it can be seen that one system is simply the reverse of the other. When one or the other is simply "*turned around*," the force systems are identical. In other words, lingual root torque is simply a tip-back bend *turned around*. If at all confusing, remember the early rule regarding long and short sections which indicate the direction of the forces present, while stating that the bracket or tube closest to the bend contains the largest moment. This is an effective memory system until the subject of mechanics is discussed in more depth. However, understanding is more important than memory.

Occlusal planes may be altered by couples present to balance net moments while occlusal planes already in balance with equal and opposite moments require no balancing forces (*couples*). Altered occlusal planes can be desirable or undesirable. This is a choice that can be made by the orthodontist. Changes may be made to alter the amount of anterior teeth to be shown or made for a number of other reasons including the relationship to the condylar path for those concerned with posterior disclusion of teeth in protrusive movements.

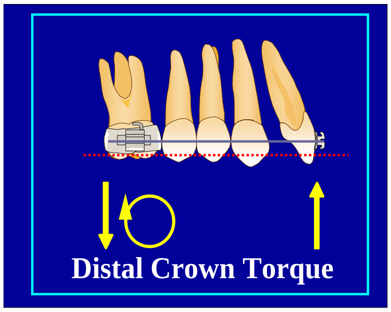


Figure 3-27

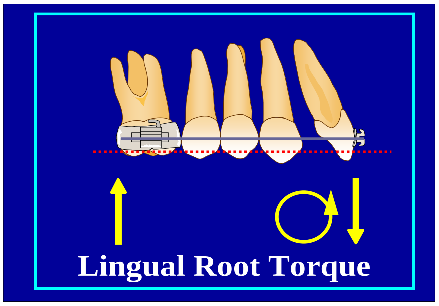


Figure 3-28

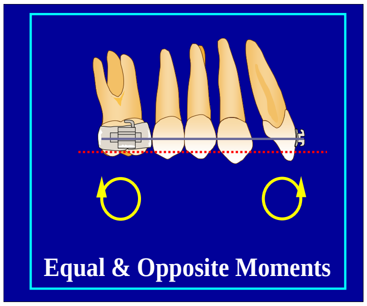


Figure 3-29

Figures 3-27 & 3-28 demonstrate a need for a balancing couple. Figure 3-29 shows balancing moments present and therefore no need for a couple. Couples are created only for *net* moments.

As this chapter comes to a close, another look at Figure 3-1 and Figure 3-3 shown at the introduction to the subject of static equilibrium might now make more sense as to why balance exists when individual weights are equal or unequal. It was first acknowledged that experience provided acceptance of the outcome. Now the *cause* of the outcome can be understood and applied in clinical orthodontics as well.

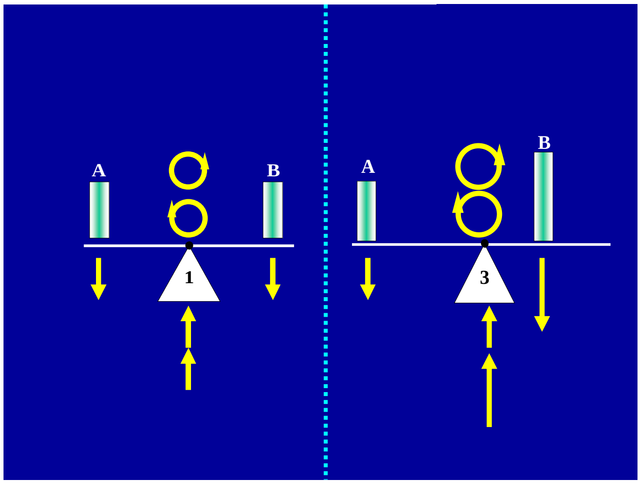


Figure 3-30

As can be seen, the illustration to the left in Figure 3-30 shows two individuals with equal weights seated at equal distances from the fulcrum. When analyzing the force system, it can be determined that the forces and moments that are shown meet the three requirements for equilibrium. So, it is not only known from *experience* that such balance occurs, but now it can be understood *why* such balance takes place. It is the *understanding* which is important as it leads to application in other areas – in this case, recognition of important force systems in clinical orthodontics.

THE SHORT STORY

Static equilibrium is an often misunderstand subject for the clinician. Such equilibrium has always been part of our lives. Examples experienced in childhood, such as two individuals of equal or unequal weight on a teeter-totter seated in various positions, demonstrates that the results are not in question, but only the *cause* as it relates to the equilibrium requirements. These same requirements apply to orthodontic treatment during wire/bracket engagement. The orthodontist is interested in what forces and moments are produced as a result of wire/bracket engagement. In static equilibrium, three requirements must be met in order to engage archwires into the bracket slots. These initial forces of insertion are referred to as *activational forces* and always meet the three requirements of equilibrium. First, the sum of the vertical forces must equal zero. Secondly, the sum of the horizontal forces must equal zero. Finally, the sum of the moments measured around a common point must also equal zero. When only two out of three of these requirements are met, static equilibrium does not exist. When recognizing that the force system meets *all* three requirements, the system is then in equilibrium. Once the three requirements are fulfilled, the net *activational* system is determined and then reversed to determine the *deactivational* system which is of concern to the orthodontist as this is the tooth-moving aspect of the system. It is not uncommon for the orthodontist to arrive at incorrect *deactivational* force systems and therefore experience unexpected tooth movements which often lead to the use of transpalatal or lingual arches.

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