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Biomechanics and Tooth Movement

A Project Submitted to
The College of Dentistry, University of Baghdad, Department Of Orthodontics in Partial Fulfillment for the Bachelor of Dental Surgery

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Certification of the Supervisor

I certify that this project entitled "**Biomechanisms and Tooth Movement**" was prepared by the fifth-year student "**Yousif Hussein Abd Alsallam**" under my supervision at the College Of Dentistry University Of Baghdad in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

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Date: 17/3/2022

Dedication

To The one who taught me all, loved me first and did everything to see me be here today, My Queen in shining armor My Mother

To the Knight who guards my skies… Takes me higher and picks me up whenever I'm down My Father

To The Guardian Angel that saved me when I glimpsed my last breathes Dr. Ziad Tariq (M. B. Ch. B – H. D. G. S.)

And lastly to the distant soul that never left my world Prof. Adil Fadhil Abbas

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Introduction

"If a body is at rest or moving at a constant speed in a straight line, it will remain at rest or keep moving in a straight line unless it is acted upon by a force"**(Verma and Gunton, 2020)**

From this perspective there's a necessity to understand what a force is Force is defined as "an influence that can change the motion of an object, it can cause an object to change its velocity as long as it has mass within"

Understanding the forces related to the tooth movement is not only relevant to orthodontist but can be appreciated by all dentists in order to provide the most appropriate care for their patients **(Viecilli et al, 2013).**

And since everyone continues as mention earlier in their state of rest or uniform motion unless it is compelled to change hence we have the three sciences that are keystones to the foundation of the orthodontics, which are the Physics and Mathematics a solid grasp of these three sciences allows for application in three areas **(Viecilli et al, 2013).**

1- Force application that is precise.

2- A better knowledge of clinical and histological responses to varied force magnitudes.

3- Improving the appliance's design.

Also the response can be found at three crucial levels (Clinical, Cellular, and stress-strain level of activity) within the investing tissue.

As It is well known the (**Stomatognathic system**) is made of the two main jaws respectively the Maxillae (representing the upper jaw) and the Mandible (representing the lower jaw) alongside the teeth which are embedded within these jaws and surrounded by the soft tissue which is lips and the buccal mucosa. **(Fábián et al, 2016).**

Aim of the Study

To provide an in-depth look to the core fundamentals that relate to the biomechanics of tooth movement to better understand and utilize them in a successful orthodontic treatment.

Chapter One - Review of Literature

1.1 An Indepth Look to the Principles of Forces

Orthodontic treatment is based on the principle that if prolonged pressure is applied to a tooth, tooth movement will occur as the bone around the tooth remodels , in which Bone is selectively removed in some areas and added in others. Because the bony response is mediated by the periodontal ligament, tooth movement is primarily a periodontal ligament phenomenon **(McCormack et al, 2014).** Forces applied to the teeth can also affect the pattern of bone apposition and resorption at sites distant from the teeth, particularly the sutures of the maxilla and bony surfaces on both sides of the temporomandibular joint, thus the biologic response to orthodontic therapy includes not only the response of the periodontal ligament but also the response of growing areas distant from the dentition **(McCormack et al, 2014).**

During masticatory function, the teeth and periodontal structures are subjected to intermittent heavy forces. Tooth contacts last for 1 second or less; forces are quite heavy, ranging from 1 or 2 kg while soft substances are chewed up to as much as 50 kg against a more resistant object. When a tooth is subjected to heavy loads of this type, quick displacement of the tooth within the PDL space is prevented by the incompressible tissue fluid. Instead, the force is transmitted to the alveolar bone, which bends in response **(McCormack et al, 2014)**.

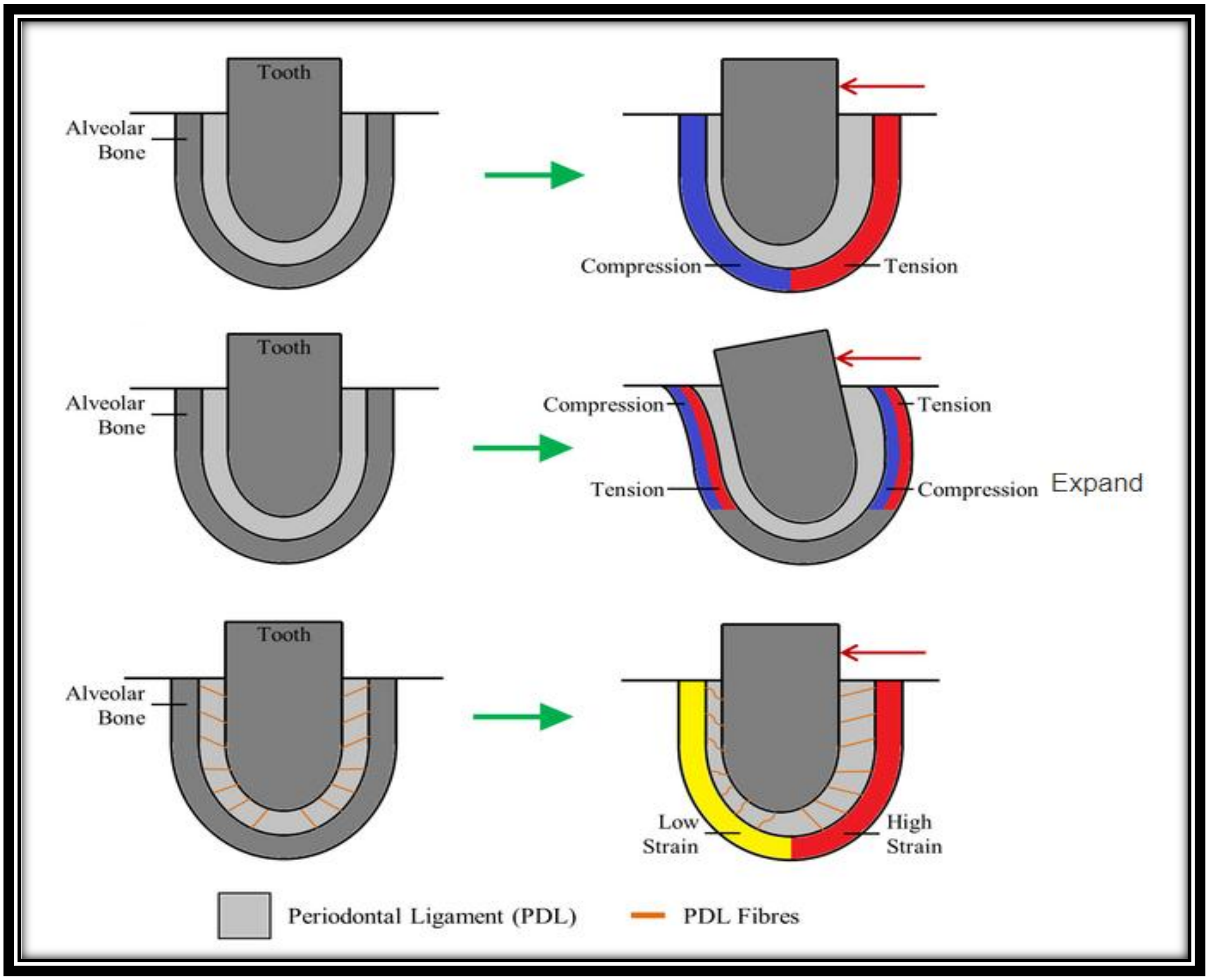


Figure (1); Bone Bending due to transformation of forces from the PDL to it, **(McCormack et al, 2014).**

The resistance provided by tissue fluids allows normal mastication, with its force applications of 1 second or less, to occur without pain The response to sustained force against the teeth is a function of force magnitude: heavy forces lead to rapidly developing pain, necrosis of cellular elements within the PDL Lighter forces are compatible with survival of cells within the PDL and a remodeling of the tooth socket by a relatively painless "frontal resorption" of the tooth socket **(McCormack et al, 2014).**

In orthodontic practice, the objective is to produce tooth movement as much as possible by frontal resorption, recognizing that some areas of PDL necrosis and undermining resorption will probably occur despite efforts to prevent this (Hovolandsdal et al, 1986).

In order to take advantage from the mechanism of bone resorption and remodeling correctly using the forces, there are some marks to be mentioned regarding the body to be moved and its center of mass (The Tooth) and how the forces correlate to it starting with **(Profitt and Henry, 2014).**

Every single object that exists with a mass that defines it exist with a point that keeps it perfectly balanced, This point is further explained as the point that a body concentrates its weight to, Termed the “Centre Of Gravity” **(Nicoli, 1985).**

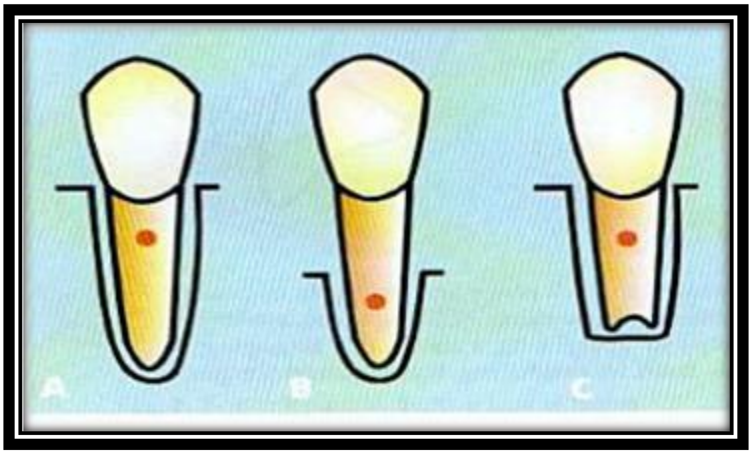
There is the problem of teeth’s inability to move in a free manner since they’re restricted by the investing tissues around the roots (The PDL), to overcome this obstacle we need to utilize the center of resistance.

1.2 A center of resistance

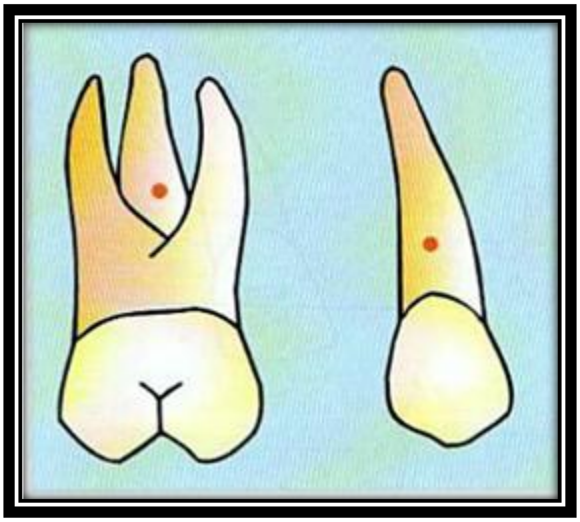
In a teeth, Is mainly a “Single point on the tooth that a single force passes through it” **(fig2,3)** and is constant. Different teeth have different centers of resistance, A center of resistance is influenced by the alveolar bone height and the root length **(Smith and Burstone, 1984).**

For Single Rooted Teeth → Between one third and one half of the root.

For Multi Rooted Teeth → Between the roots, about 1-2mm apical to the furcation area **(Zymperdikas et al, 2012).**



Figure(2); Center of resistance (A) normal alveolar bone, (B) alveolar bone loss results in apical shift of center of resistance, (C) root resorption and shortening results in more coronal center of resistance **(Graber et al, 2016).**



Figure(3); Centre Of resistance of multirooted and single rooted teeth **(Graber et al, 2016).**

However Centers of resistance are prone to change under the effect of certain factors like root length, alveolar bone height, length of the root.

A tooth with a longer root will have its center of resistance placed more apically, Same rule applies if the alveolar crest is higher it'll result in the center of resistance to be set further coronally **(Viecilli et al.,1984).**

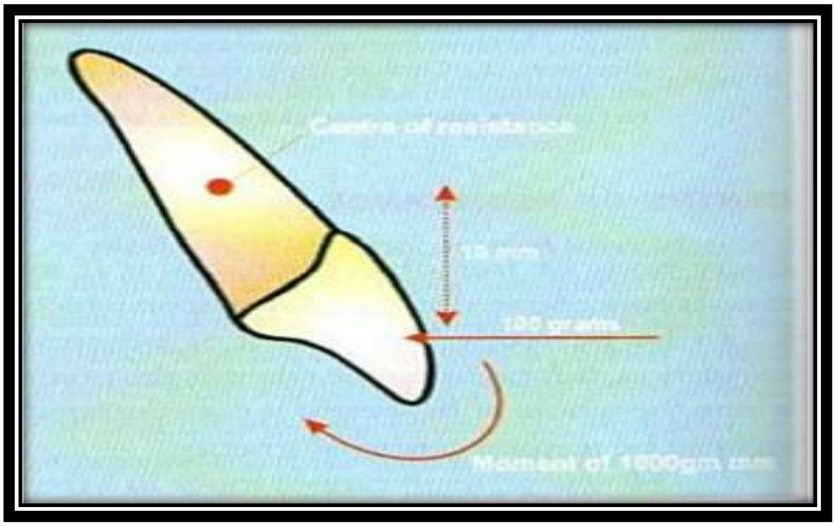
The use of forces needs to be measured and monitored with professionalism to avoid any unwanted side effects or uncontrolled forces that could damage and create new problems, That can be measured with the use of moment **(Viecilli et al, 1984).**

1.3 Moment

Is the rotational potential of a force seen from a single axis or mathematically expressed as the (magnitude of force x the distance) and the unit used is gram millimeters (gram for the force and millimeters for the distance) **(Hocevar, 1981) (fig4).**

Moment is subjected to two variables that effect it which are the magnitude of the force and the distance from the center of the resistance of the object to be moved But they're able to be manipulated to achieve the desired force.

A tooth follows a non linear or straight path to reach its final destination hence the change of its center of resistance several times **(Marcotte, 1990).**



Figure(4); Moment is calculated by multiplying the magnitude of force by the perpendicular distance of the line of action to the center of resistance **(Profitt and Henry, 2014).**

1.4 Couple

Consists of two forces of equal magnitude but opposite in direction, with parallel but non-colinear lines of action (**fig 6).** When two forces are applied in this manner the resultant produced is a pure moment (The translatory effect of the individual forces gets cancelled) **(Skinazi et al, 1994).**

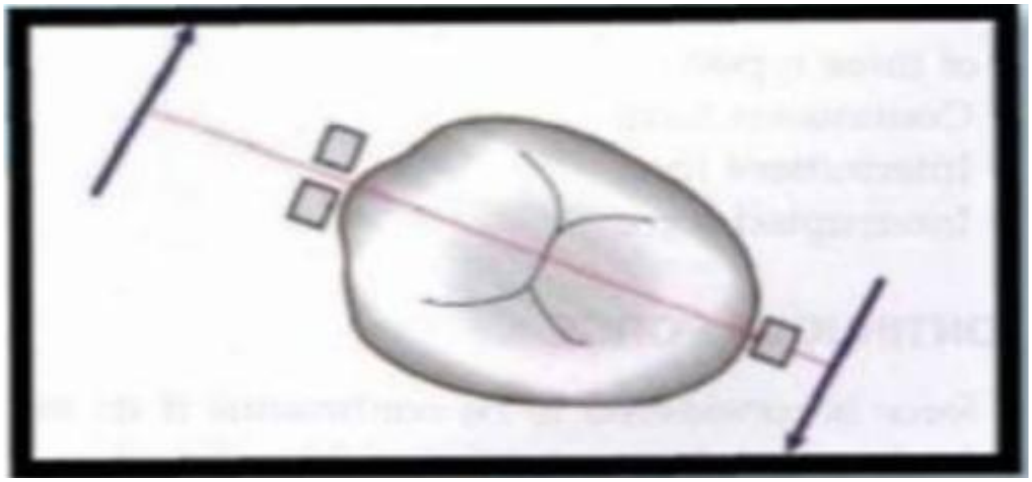
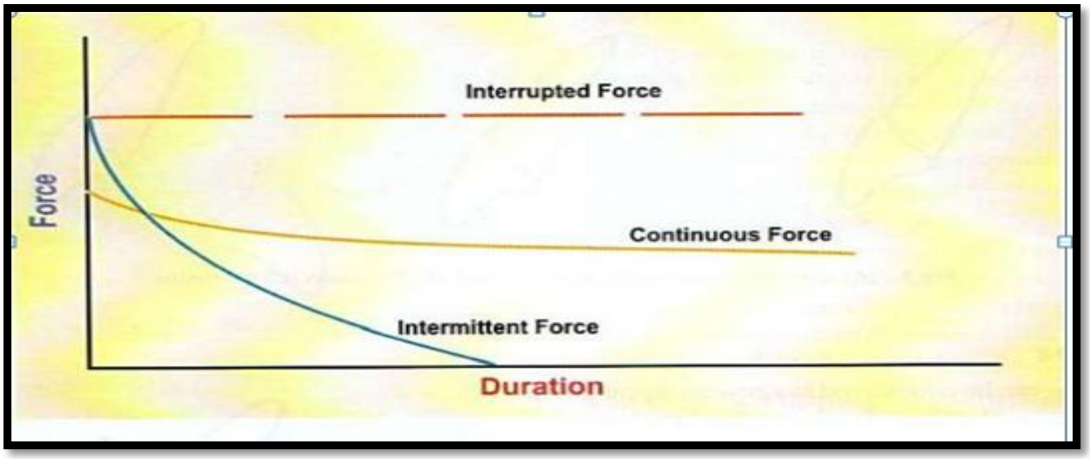


Figure (5); Couple Consists of two forces of equal magnitude but opposite in direction **(Skinazi et al, 1944)**.

1.5 Types of Forces

Since it's been already established that in order to correct the occlusion it's must to have the effect of controlled forces to achieve this goal, and it's also required for the operator to be skilled by distinguishing type, amount and direction of forces to be used that's why forces are divided into **(Profitt and Henry, 2014).**



Figure(6); Graph showing the different types of forces **(Profitt and Henry, 2014).**

1.5.1 Interrupted Forces

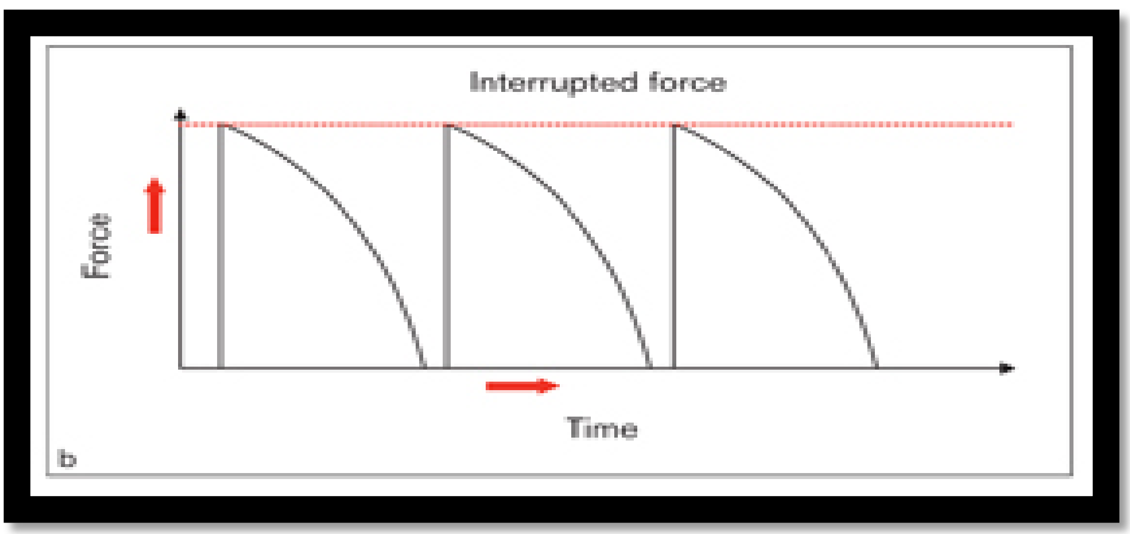
This force is inactive for long periods of time **(fig8),** It often is characterized by long term force, But it has its requirements (**Profitt and Henry, 2014)**.

A-It Should deliver heavy forces.

B- There should never be any force decay overtime.

C-There should be a specific magnitude pattern e.g. 200-300gms of force 10-14 hours a day.

D-Most importantly the period of each day must be sufficient to keep the periodontal ligament healthy over the total period of time of use of the appliance(**Profitt and Henry, 2014)**.

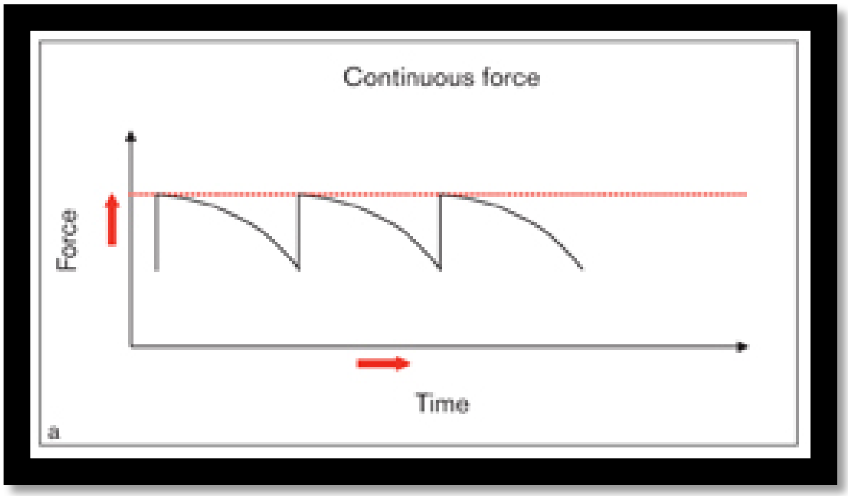


Figure(7); a graph demonstrating interrupted forces (**Profitt and Henry, 2014)**.

1.5.2 Continuous Forces

An active force that decays overtime during periods e.g. light wire appliance **(fig9),** for it to work continuously the appliance component has to be highly flexible and the activation must be done in a low force level (due to high forces causing root socket resorption) hence they shouldn't interfere with the blood vessels, nutrition nor occlude more than an ever so slightly percentage of them, They Lack rest periods and they can be tolerated **(fig9) (Jacobson, 1979) .**

Figure(8); Advanced Lightwire Appliance **(Delz, 2009).**



Figure(9); Continuous force **(Norton, 2000).**

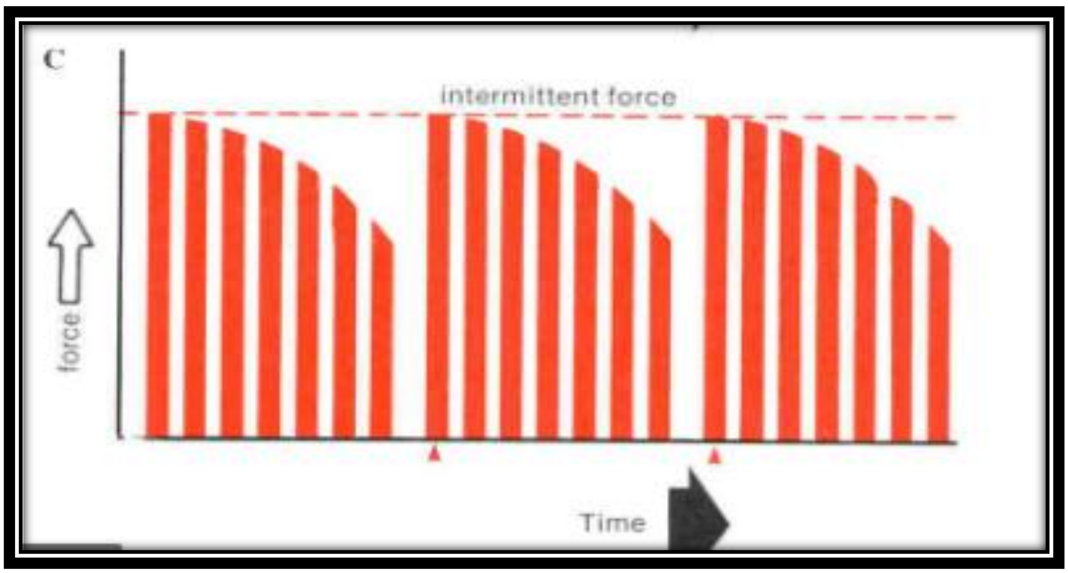
1.5.3 Intermittent Forces

Similar to the continuous force in the way it decays to zero magnitude or close to it prior to the appointment **(fig11)** e.g. removable active plates. Has its own requirements that are **(Graber et al, 2016).**

1-The appliance components should have high stiffness.

2-The initial Activation should be twice the expected corresponding soft-tissue deformation.

However, Due to the high activation force, this results in a higher force being exerted on the tooth and also leads to undermining resorption.



Figure(10); Intermittent Forces **(Norton, 2000).**

Intermittent forces are produced by all patient-activated appliances such as removable plates, elastics and headgears as seen in **(Islam and Alam, 2017) (fig12).**

Figure (11); Headgear as an appliance of intermittent forces **(Islam and Alam, 2017).**

1.6 Types of Tooth Movements

The main goal of orthodontic treatments is to move a tooth into a more preferable location, and since a tooth is subjected to move in 3 planes of the space which are (Coronal, Sagittal, Transverse), tooth movements are as follows **(Nanda et al, 2021).**

1.6.1 Tipping movement

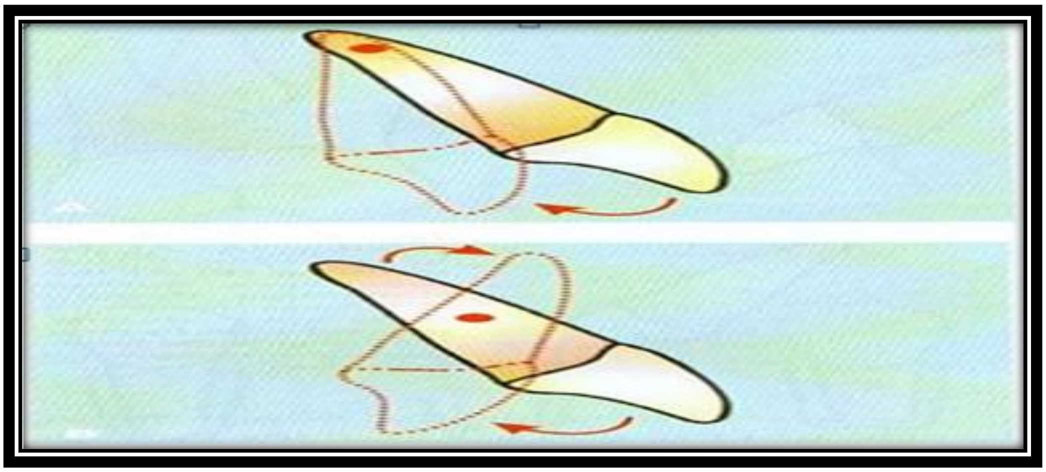
one of the simplest types of tooth movement (A single force applied to the crown which results in the movement of the crown towards the linear direction of the force however the root moves in the opposite direction**(fig13)**and is also divided into **(Graber et al, 2016)**.

A-Controlled Tipping: Controlled tipping occurs when force is directed to a center of rotation at its apex, resulting in a lingual movement with minimal movement of the root in the labial direction **(Graber et al, 2016)**.

B-Uncontrolled Tipping: this movement is different in the tooth moves about a center of rotation "apically" and very close to the tooth's center of resistance**(Graber et al, 2016)**.

Uncontrolled Tipping = Crown movement in one direction BUT root moves in other direction.

Tipping force magnitude is required to be between 50-75(gm) (Pandula,2015).



Figure(12); Tipping Tooth movement, First is the Controlled Tipping Followed by the Uncontrolled Tipping of a tooth **(Profitt and Henry, 2014).**

1.6.2 Bodily Movement

As established earlier when a force gets exerted on a tooth surface the line of action will pass through the center of resistance and all the points of the set tooth will move an equal distance in the same direction **(Marcotte, 1990).**

Bodily Movement magnitude is required to be between 70-120 force(gm) (Pandula,2015).

◆**And divided to:**

A) Intrusion movement.

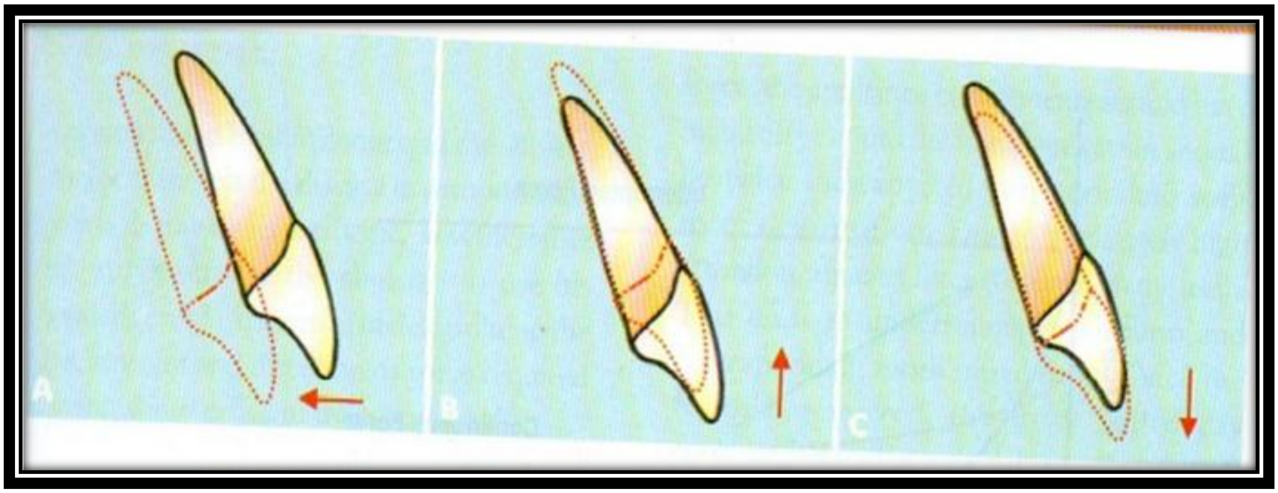
B) Extrusion movement.

A) Intrusion: Bodily movement of the tooth apically.

Intrusion force magnitude is required to be between 15-25(gm)(Pandula, 2015).

B) Extrusion: Bodily movement of the tooth occlusally **(Zwemer, 1985).**

Extrusion force magnitude is required to be between 50-75(gm) (Pandula, 2015).



Figure(13); (A) Translation or bodily displacement (B) Intrusion (C) Extrusion

(Zwemer, 1985).

1.6.3 Torquing

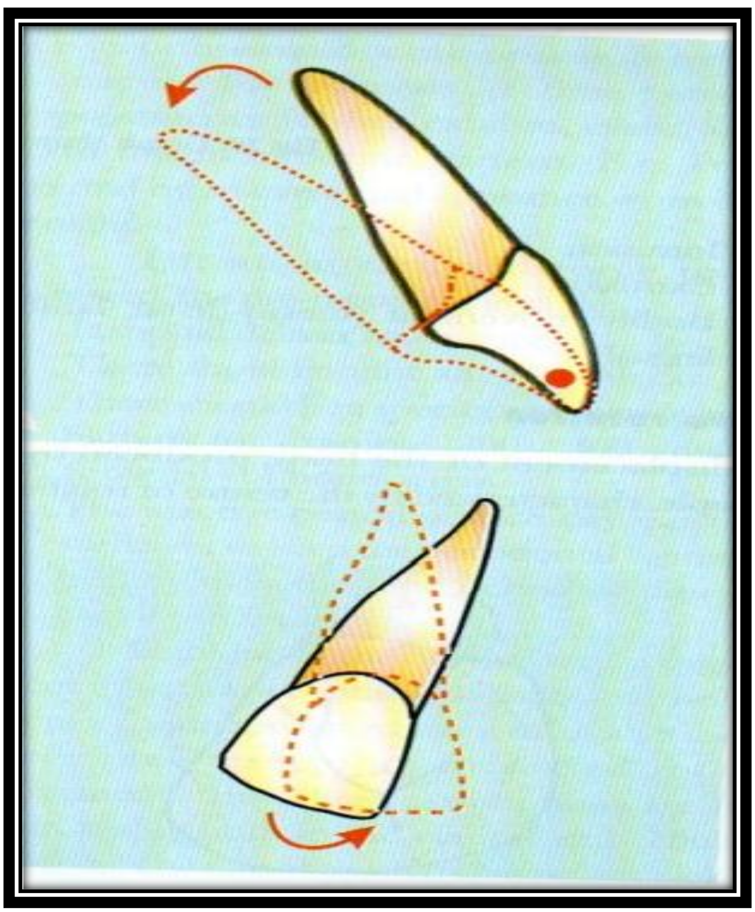
is the opposite of tipping (Lingual movement of the root) **(fig15)** (**Graber et al, 2016) (fig15A).**

Torquing force is required to be between 75-125(gm)(Pandula,2015).

1.6.4 Uprighting

Sometimes the teeth are tipped in a certain direction mesiodistally different from the root direction, uprighting these teeth helps in parallelizing the root and crown together **(Rego, 2017)(fig15B).**

Root uprighting magnitude is required to be between 75-125(gm)(Pandula, 2015).



Figure(14); Torquing and Uprighting of Teeth **(Graber et al, 2016).**

1.6.5 Rotation

1.6.5.1 Pure Rotation

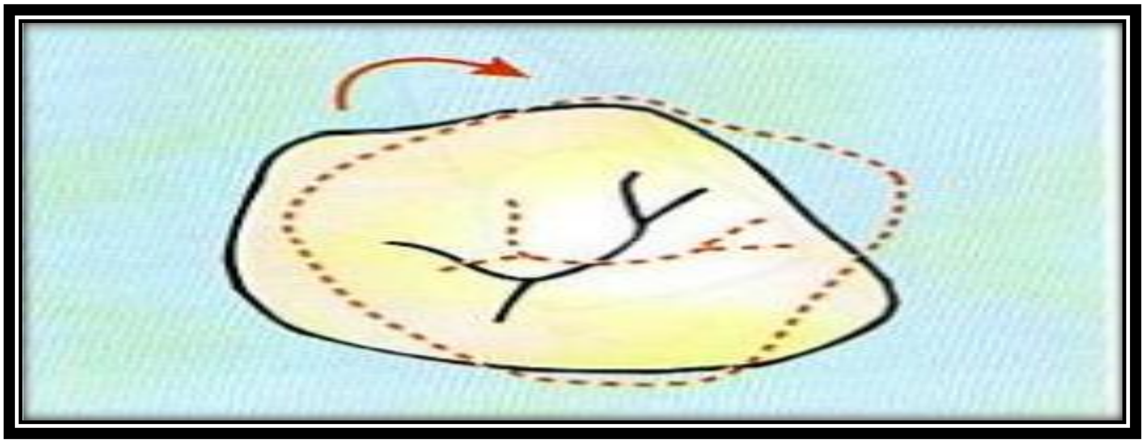
Pure rotation is defines as: A displacement of the body produced by a couple characterized by the center of rotation coinciding with the center of resistance i.e. the movement of points of the tooth along the area of a circle, with the centre of resistance being the centre of the circle. Pure rotations can be divided into 2 types **(Zilberman, 1994).**

A) **Transverse Rotation:** Those tooth displacements during which the long axis orientates e.g. tipping and torqueing **(Ormiston, 2005).**

B) **Long-Axis rotation:** Here the angulation of the long-axis is not altered e.g. rotation of a tooth around its long axis **(Ormiston, 2005).**

1.6.5.2 Generalized Rotation

any movement that is not pure translation of rotation can be described as a combination of both movement (which are translation and rotation and can be termed generalized rotation. This type of movement can be seen during routine clinical practices) **(Graber et al, 2016).**



Figure(15); Rotation **(Graber et al, 2016).**

Rotation force magnitude is required to be between 50-75 (gm) (Pandula,2015).

1.7 Biomechanical Hypothesis Related To Tooth Movement

A lot of theories have been suggested due to the nature of orthodontic tooth movement being a result of a biological response to the interference in the physiological equilibrium of the dentofacial complex by an externally applied force **(Reitan, 1957).**

The concept of tooth movement has been extensively investigated since the onset of the twentieth century. From the classic reports by **(Sandstedt, 1904)**the race was set for the exploration of the foundation of orthodontic tooth movementSome of the theories that explain tooth movement mechanisms are: **(Ren et al, 2003)**.

1.7.1 Kingsley's hypothesis

Kingsley (1881), stated that slow orthodontic tooth movement is associated with more favorable tissue remodeling changes (the mechanisms of resorption and deposition of alveolar bone) while quick movements displace the entire bony lamellae along with the teeth while retaining their functional and structural integrity He attributed the features to a number of factors including (Elasticity, Compressibility, and flexibility of the bone tissue) **(fig17).**

Originalartiklar.

Einige Beiträge zur Theorie der Zahnregulierung

von CARL SANDSTEDT.*

Einleitung.

Die Orthodontie, oder die Lehre von der Regulierung der Zähne, ist ein ziemlich neuer Zweig der Zahnheilkunde. Noch in der Mitte des 19:ten Jahrhunderts widmete die damals erscheinende odontologische Litteratur den Anomalien in der Zahnstellung, wie der Behandlung derselben keine oder wenig Aufmerksamkeit. Es ist auch ganz natürlich, dass man zu einer Zeit, wo die Tätigkeit des Zahnarztes sich im wesentlichen auf das Ausziehen schmerzender Zähne und auf Beschaffung eines mehr oder weniger zufriedenstellenden Ersatzes für dieselben beschränkte, einem

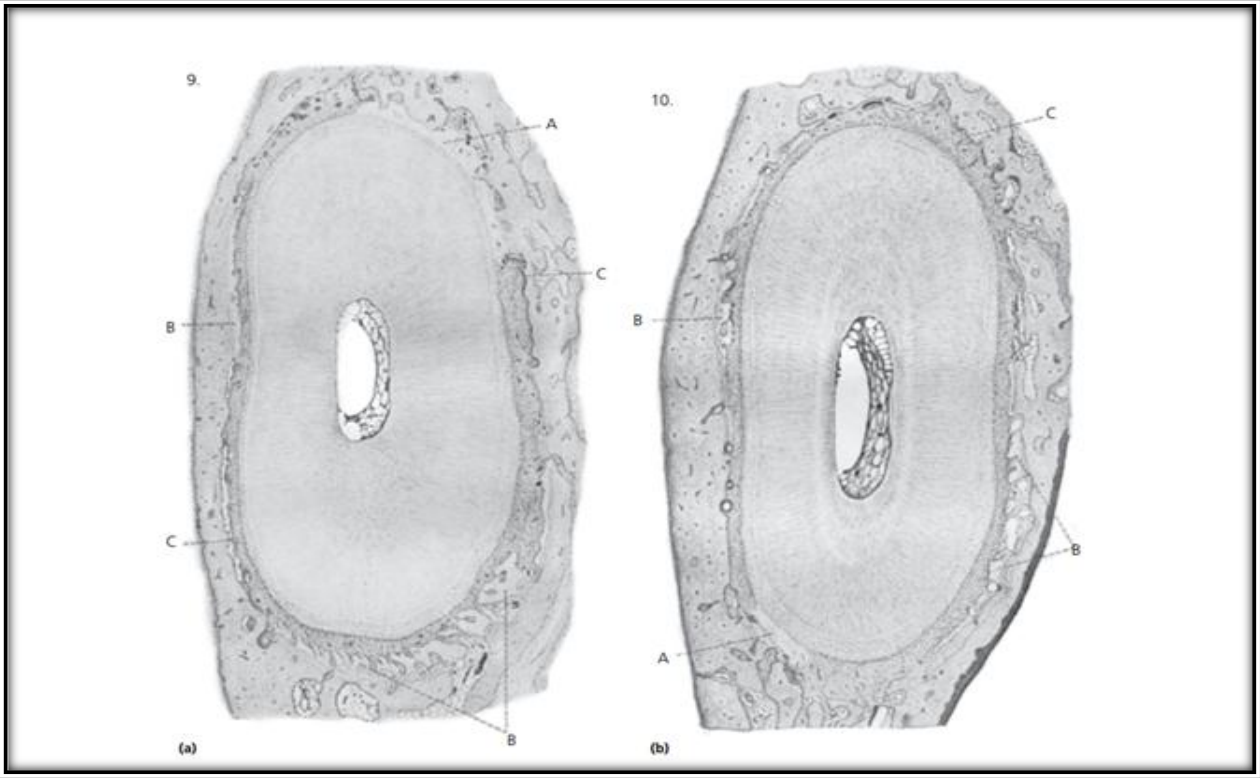
* Der Zahnarzt Carl Sandstedt starb als Lehrer am Zahnärztlichen Institut des Schwedischen Staates im Laufe dieses Jahres. Vorliegender Artikel beleuchtet ein besonders interessantes, wiewohl noch unerforschtes Gebiet innerhalb der Zahnheilkunde. Leider war es dem Verfasser nicht vergönnt, seine Arbeit über die Theorie der Zahnregulierung abzuschliessen. Was er hinterlassen hat, macht nämlich nur einen Teil der beabsichtigten Arbeit aus, ist aber nichtdestoweniger der grössten Aufmerksamkeit wert. *Die Red.*

Figure (16); Page from Sandstedt's Original Article On the histological Studies of the tooth movement published in 1904.

1.7.2 Walkhoff's Hypothesis on the biology Of OTM

Walkhoff (1890), writing shortly after Kingsley's contribution, noted that "movement of a tooth consists in the development of distinct stresses in the bony structure, its consolidation in the compensation of these tensions."

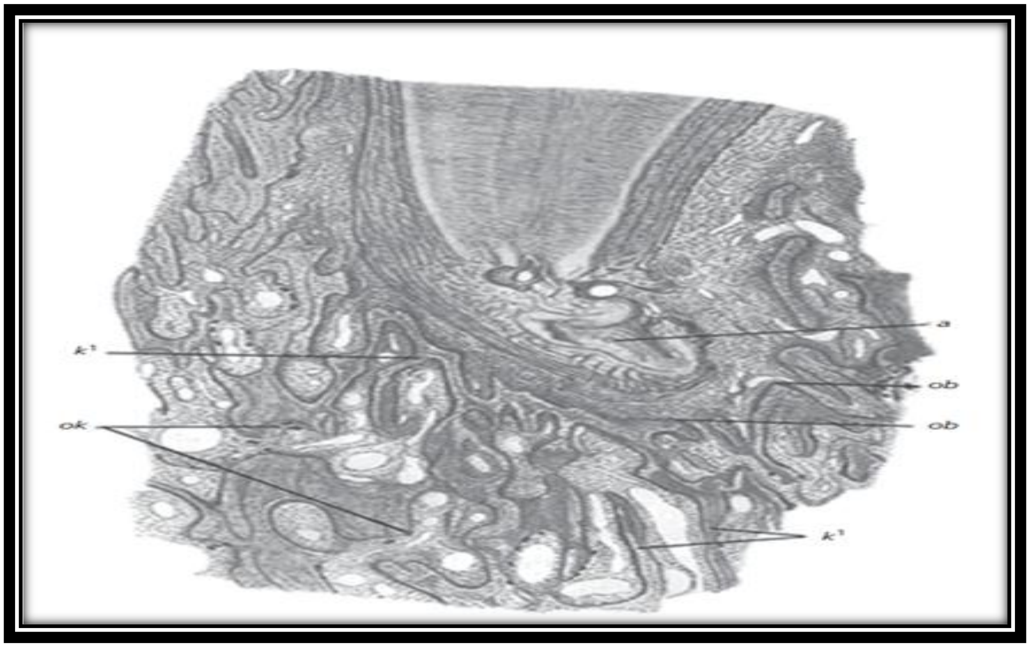
The elasticity, flexibility, and compressibility of bone, as well as the transposition of histology parts, were crucial to Walkhoff's idea (such as the PDL). He also noted that despite all remodeling modifications, alveolar bone retains its thickness owing to bone transformation or apposition during the consolidating (retentive) stage **(Krishnan, 2021).** He stressed the necessity of retention, claiming that "osteoid tissue has little to do with tooth movement." Following suit with the Figure below demonstrating horizontal sections.



Figure(17); Plate III from sandstedt's original article showing horizontal sections through the right maxillary canine; The direction of movement is towards the top (Source: Standstedt, 1904-1905) A section cut in the close proximity to the alveolar rim. (A- at the site of presumptive buccal side of the root, a thin layer of lighter staining new bone is demarcate from the old bone by a von Ebner line) (B, A section through the middle third of the same tooth (e.g. in dogs, the pulp canal expands towards the middle third of the rooth before narrowing towards the apex) General remodeling activity at the bone PDL interface is seen but evidence of the accelerated bone formation is absent **(Sandstedt, 1905).**

1.7.3 Oppenheim's transformation hypothesis

Oppenheim (1944), conducted OTM on a juvenile baboon, wherein he performed all sorts of tooth movements (labial, lingual, intrusion, extrusion, and rotation), with a split mouth design (where one side of the dental arch is operated upon, while the other side serves as control). He processed the jaw tissues histologically, and concluded that The bony tissue, be it compact or cancelleous, reacts to pressure by a transformation of its entire architecture; this takes place by resorption of the bone present and deposition of new bony tissue; both processes occur simultaneously **(Oppenheim, 1944)**.

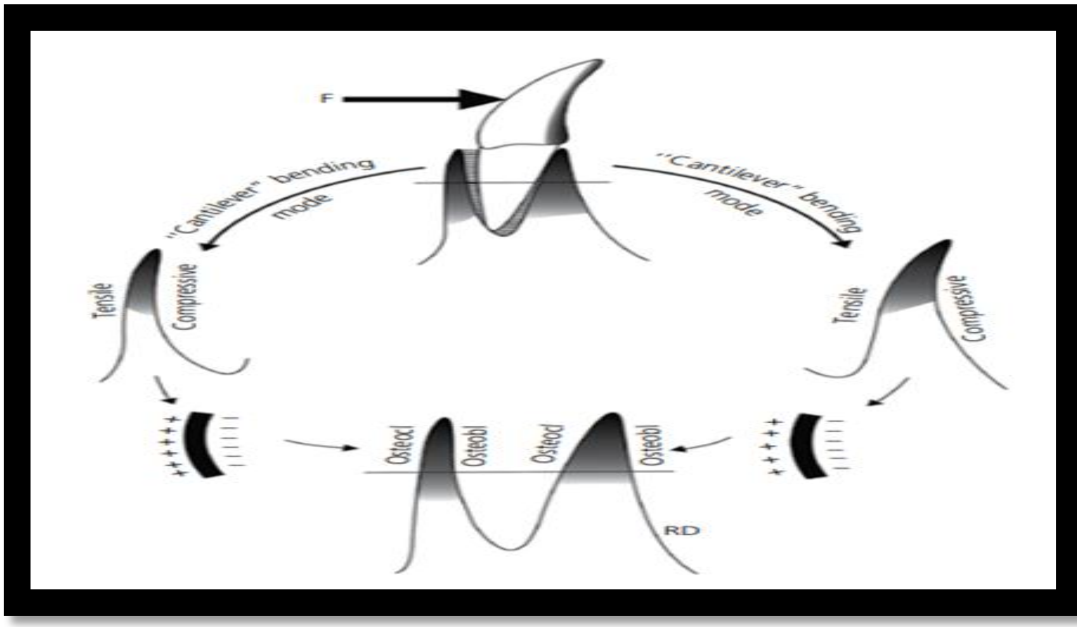


Figure(18); The spongy bone spicules at the root apex appears as long thin buttresses stretching from the depth toward the root apex **(Oppenheim, 1944)**.

1.7.4 The bone bending hypothesis

Baumrind (1969), stated that “when orthodontic appliances are placed forced delivered to the tooth are transmitted to all the tissues in the region of force application. When bone is held under mechanical forces, the remodeling and reorganization process is accelerated not only in the lamina dura, but also on the surface of every trabeculum within the corpus of the bone. The force/stress directed to the teeth will be dissipated by the development of stress lines in the deflected bone and becomes a major stimulus for altered biological activity, this theory helped explain the phenomena behind.

- Relative slowness of mass movements, and relative rapidity in the alignment of crowded anterior teeth.
- The rapidity in which teeth can be moved into an extraction site.
- The appearance of an axis of rotation beyond the apex of the incisors. The logic of the pressure–tension hypothesis makes it mandatory to have the axis between the apex and the alveolar crest.
- The relative rapidity of tooth movement in children.



Figure(19); Behavior of the bone during orthodontic tooth movement the net force compression and tension applied by the leading edge of the tooth deforms the alveolar bone towards the root **(Melsen et al, 2021).**

Summary: our ancestors noticed, millennia ago, that malposed teeth can be corrected by the application of mechanical forces to the crowns of the accused teeth with the passage of time, a numerous number of devices were used and created and were superior to other counterparts for the same aim, The inability to determine which of those gadgets would be best for clinical use was limited by the paucity of biological information that could support most of the claims made by their inventors. However, there was a breakthrough with the introduction of histology into orthodontics at the start of the twentieth century. The visualization of the response of tissues and cells to mechanical forces opened the gate to thoughtful proposals of hypotheses, to explain the reason for tooth movement. Since the following of the bone bending theory other hypotheses from this focused on the role of dynamics of tissue fluid in OTM.

Chapter Two – Discussion

As a general rule of thumb regarding the biomechanics of tooth movement, Certain aspects must be acknowledged beforehand. First being the definite type of force needed to move said tooth, the amount of force used (hence the necessity of a trained orthodontist to avoid any unnecessary movement) and the appliance required to achieve this goal, different theories have come and some of them fell short of actually explaining the key principle behind the core mechanic of achieving the desired goal of mobilizing a tooth to a more strategic place **(Norton,2000).**

Understanding the aspect of tooth movement requires the thorough comprehension of it being a time consuming process and not an immediate process due to the risk of injury to the accused tooth also the avoidance of excessive force which leads to an unwanted tooth movement which can be detrimental to the results of the treatment **(Naish et al, 2017).**

Chapter Three- Conclusion

Based on the interpretations of previous data mentioned of the mechanisms and biological core mechanisms of a tooth movement, it can be concluded that a tooth can be moved in a controlled manner of force in 3 different planes to a more desired occlusion, Utilizing the physical principles related to the types of forces that can be used by different appliances while focusing mainly on the advantage of the two key features of the jaw bones which are the resorption and deposition of bone.

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