

BIOLOGICAL PRINCIPLES OF ORTHODONTIC TOOTH MOVEMENT: A REVIEW ARTICLE

ABSTRACT

Orthodontic tooth mobility is discussed in this article, and the numerous concepts or theories of movement of tooth and the phases through which a tooth undergoes after application of forces. The effect of orthodontic pressure exerted on the dental architecture promotes movement of tooth through remodeling, which is the growth and resorption of alveolar bone. These forces can either be light forces or heavy forces depending upon their magnitudes. Biological aspects of tooth movement changes in accordance with the magnitude, force, time span and direction of force exerted. Variations in force application can be decided based on the kind of movement of tooth desired. These forces result in complex physiological events, cellular events in the surrounding tissues and, release of various chemical mediators to re-establish the equilibrium which gets interrupted by applying forces.

Recently, many researches are going on how to enhance the speed of movement of the tooth with light forces so as to reduce the damage caused by the heavy forces, reduce the treatment time overall and treatment planning which results in minimal adverse effects.

Year : 2019, Volume : 10, Issue : 8, heavy force, orthodontics, tooth movement, medications, light force, periodontal ligament

INTRODUCTION

When a force is exerted on tooth's crown, it gives rise to mechanical energy which is transformed into biological reaction, resulting in orthodontic tooth movement.(1)

Clinicians have always found it fascinating to acknowledge the basic principle of movement of tooth, for the sake of reducing the overall regimen, enhance the patient's satisfaction and minimize the adverse effects, such as white spot lesions, permanent enamel damage, gingival recession and root resorption, caused by prolonged orthodontic treatment, which is aimed at alignment of teeth (2) and periodontitis which is a persistent inflammatory condition that affects the periodontium.(3) The concept that brackets create a great environment for bacteria to collect and grow is the core cause of white spot lesions.(4)

So, researchers have investigated if it is possible to move a tooth at a greater rate than it is with traditional techniques to shorten the time period of the treatment.

Physiological effects of movement of tooth are a complicated process, involving both dental and periodontal tissue remodeling. Newton's Laws govern the physical characteristics of movement of tooth caused by forces applied on it. Through signaling pathways and receptor cells, the tooth's biological system reacts to fluctuations in magnitude of pressure, duration of application along with the directiveness, ultimately resulting in bone modification and movement of tooth.(5) The goal of all the cellular events that occur is to re-establish a momentarily interrupted equilibrium by simply applying a force.(6)

In the last few years, the tooth movement research has shifted its focus from understanding the functioning of cells to analyzing the regulation on molecular level and effect of these events, which involve a variety of substances such as neurotransmitters, cytokines, arachidonic acid, colony stimulating factors (CSF) and growth factors.(6)

By a biological point of view, the tissue response which is witnessed during movement of tooth is impacted by a number of things, that can either be related to natural occurrence (shape of root, bone type. . .) or treatment (type of treatment, type of movement, duration of force applied) (7)

From technical point of view, the advancement of technical metals has resulted in a wide spectrum of wires, allowing for the employment of optimum forces which facilitate the movement of tooth.(8)

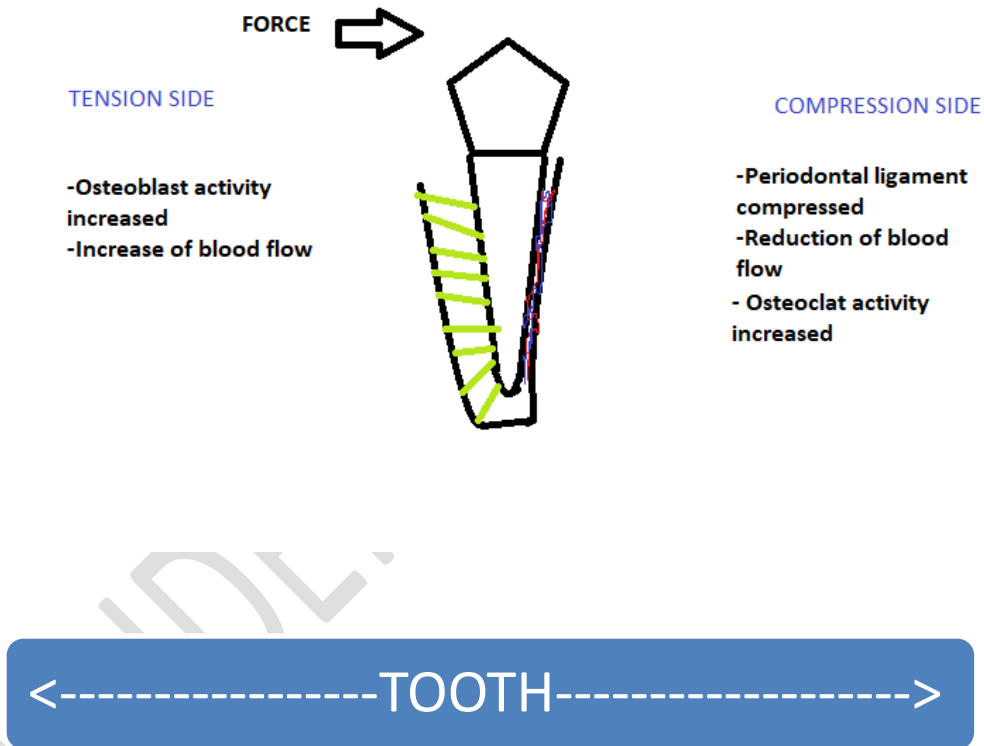
PERIODONTIUM'S RESPONSE TO TOOTH MOVEMENT

- The supporting and investing attachment of alveolar bone to the teeth is known as periodontium. The part of gingiva facing the tooth and periodontal ligament (PDL) soft tissues together with the bone lining the alveolus and cementum hard tissues, are all included in periodontium.(5)
- Many changes occur inside the supporting tissues of the tooth during its movement, depending upon the amount, path, and time span of the force exerted, as well as the patient's age and growth condition.
- The treatment planning is based on the notion that if a tooth is subjected to persistent mild pressure, movement will occur in it when the surrounding bone remodels.
- The mandible, unlike the maxilla, is a membranous bone with a modest resorption rate.(9)
- The bone is removed deliberately in some regions (compression site) while in others it builds up (tension site), resulting in the movement of tooth.
- Since periodontal ligament mediates the bone response, tooth movement is predominantly a PDL phenomena, which can be demonstrated by changes in blood flow through periodontal ligament as on the compression side, it decreases whereas on the tension side, it increases.(10)

Assuming that the loading force remains constant, biologically active agents are released such as cytokines (for example: Interleukin- 1b) and prostaglandins, blood flow influences the oxygen tension (ratio of oxygen and carbon dioxide levels) and chemical environment pretty quickly (in few minutes). These chemical mediators activate activity of cells differently in the tension and

compression regions of the periodontal ligament, resulting in bone resorption on the compression side and bone growth on the tension side. Under extreme pressure, flow of blood is blocked completely, leading to cell death (hyalinization). As an outcome, there is minimal maturation of osteoclast within the constrained periodontal space; rather, the resorption that dissolves the lamina dura around the squeezed periodontal ligament is due to delay in development or recruitment of osteoclasts from surrounding bone marrow area.

Thus, when heavy force is applied on the teeth, it takes 7-14 days for them to move. Moreover light forces, just limits blood flow, allowing osteoclasts to be recruited quickly either via blood flow or inside the periodontal ligament on a localized basis. These osteoclasts dissolve the lamina dura as part of the frontal degradation procedure. Soon after, movement of tooth begins, usually a few days after the application of light pressure.(5)



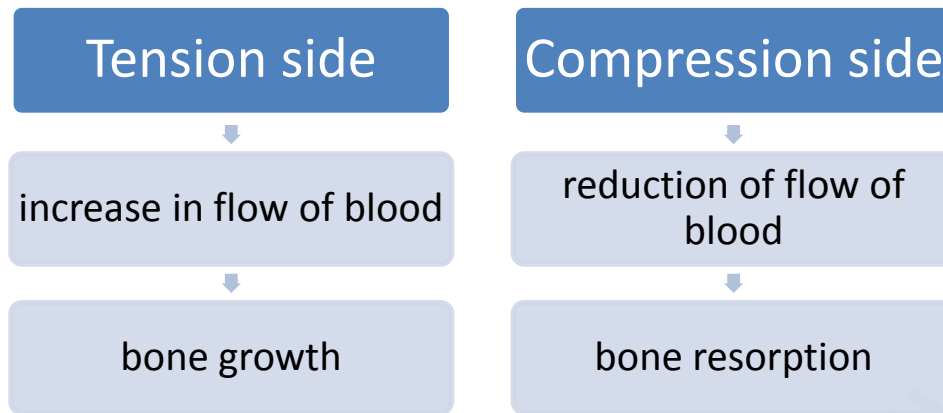


Chart 1 .PHASES OF TOOTH MOVEMENT

Three phases of movement of tooth were postulated by Burstone in 1962. They were:-

- (i) Initial phase
- (ii) Lag phase
- (iii) Post lag phase

The initial phase begins once the force is exerted on the tooth. Due to the shifting of the tooth in the periodontal space, the movement is fast. This phase normally lasts anywhere from 24-hour period to a 2-days period. When the tooth moves, it moves within the bony socket. The periodontal ligament is compressed and stretched as a consequence of the pressure imparted to the tooth, causing extravasations of vessels, recruitment of osteoblast and osteoclast progenitors and chemo-attraction of inflammatory cells(11)

Following the initial stage, there is a lag interval or phase wherein the mobility of tooth is negligible or non-existent. This phase is caused by hyalinization of the squeezed periodontal ligament. The movement will not occur until the cells have eliminated the necrosed tissue. During this phase, the movement is paused for a period of time ranging from a few weeks to a month, during this time all the necrotic tissue is eliminated, along with nearby resorbed bone marrow. Macrophages, osteoclast cell and foreign body giant cells eliminate the necrotic tissue from the crushed bone and periodontal ligament locations. (11)

The third phase is the post lag phase, which occurs few months after the initial force application and is characterized by gradual or abrupt increase in the movement of tooth. It has been postulated that during tooth displacement, the necrotic tissue develops and is removed continuously.(12)

CONCEPTS OF MOVEMENT OF TOOTH

The orthodontic load exerted on the dental architecture promotes movement of tooth through remodeling, which is the resorption and deposition of alveolar bone. This energy is converted

into bioactivities, which isn't entirely acknowledged, although three possible tooth movement concepts have been proposed. They are:-

- (i) Bone bending theory
- (ii) Biological electricity theory
- (iii) Pressure tension theory ¹

(1.) BONE BENDING THEORY

When a tooth is subjected to orthodontic force, it is distributed to all tissues within a short distance of the load application, according to Farrar (1888). This results in bending of the periodontal ligament's solid components, teeth, and bone. (11) Because bone is more elastic than other tissues, it bends more easily, increasing the speed of movement of tooth. This also explains why teeth move very quickly at the extraction site and in pediatrics patients, where the bone is less calcified and more malleable. (13)

(2.) BIOLOGICAL ELECTRICITY THEORY

This theory was originally introduced by "Bassett and Becker" in the year 1962.

They claim that during flexing or bending of alveolar bone, "electric signals" are released, and that this is partially responsible for the movement of tooth¹. Bone bends more easily than other structures, causing an electrical flux in which electrons get transported through one crystalline mesh to another is known as piezoelectricity. (6) These signals have the following characteristics:

- (i) They have a rapid decay rate, which indicates that they start when the force is applied and then fade away quickly even if the force is sustained.
- (ii) They emit an equal response on the other side when the force is withdrawn. ¹

Two surfaces of the alveolar bone are involved in deformation:

- (i) The electronegative concave side, which increases osteoblastic activity.
- (ii) The electropositive convex side, which increases osteoclastic activity. ³

(3.) PRESSURE TENSION THEORY

Oppenheim (1911), Schwarz (1932) and Sandstedt (1904) postulated that by creating a tension and pressure side the tooth moves in the periodontal space. It illustrates why the periodontal ligament's blood flow alters. Because the periodontal ligament is compressed, on the side of pressure this modification results in decreased oxygen levels and vice versa. ¹

The two sides of periodontium are differentiated by an applied force:-

- (i) The side of pressure - the dentoalveolar ligament disorganizes in the opposite direction of the applied stress, resulting in a decrease in both the number of fibres produced and cellular multiplication due to vascular constriction combined with a loss of essential substance on the tension side.(6)
- (ii) The side of tension, in this side the ligaments becomes thicker, resulting in tightening of desmodontal fibers. The cell replication and multiplication are enhanced, possibly leading to an increase in production of fibers and hydroxyapatite crystal formation. (14) Furthermore, in an effort to keep the “thickness” of the ligament unchanged osteoclastic regions develop in the medullary spaces.(6)

Periodontal strangulation and suffocation results in necrosis of the tissue, if the applied force surpasses the “pressure” (20 to 25 gram/cm² of the “surface of root”) on the vascular bed.(15)

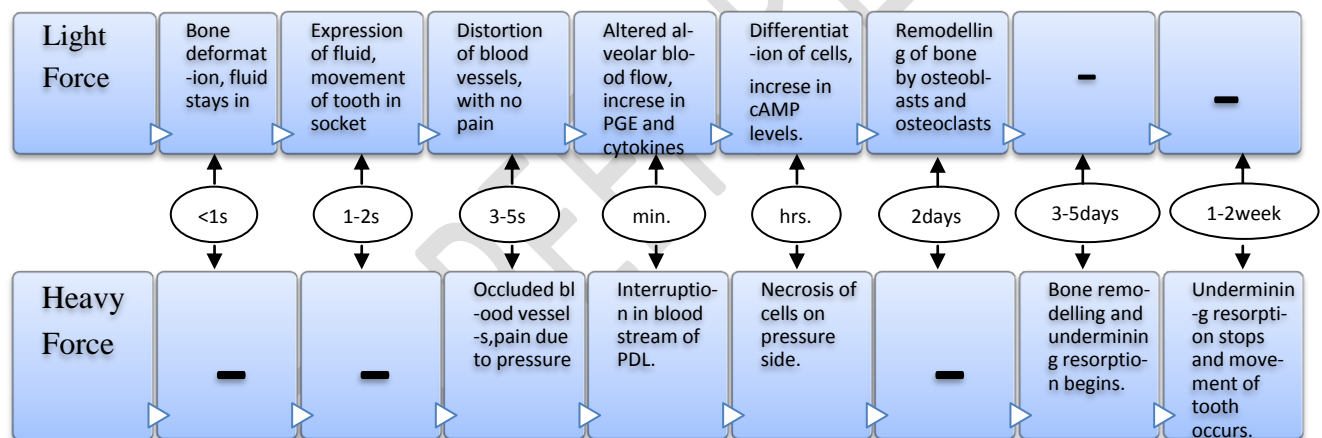


Chart 2. CONVERSION OF FORCE INTO BIOLOGICAL REACTION

Among functional components, the remodeling of bone obeys an ARIF (Activation, Resorption, Inversion, Formation) cycle, wherein the distinct stages always supervene one another in the similar order.

- (1) The phase of activation (A) - This phase involves fibroblasts secreting collagenases and osteoblasts are displaced to gain entry to the surface of the bone.
- (2) The phase of resorption (R) – This phase is characterized by the existence of functioning osteoclasts, which form a sealed acid compartment on the bone matrix to be resorbed.
- (3) The phase of inversion (I) – In this phase the “osteoclasts” vacate the area that has been resorbed and the “osteoblasts” take over.

- (4) The formative phases (F) – In this phase the osteoid tissue which are synthesized by the osteoblasts, fill the resorbed lacunae. Later, these cells mature into “osteocytes”, which “mineralize” the tissue that has been recently formed.

These reactions stop once the tissue equilibrium is reached, and a condition of rest exists. Most of the time, equilibrium between synthesis and resorption is reached, and the resorbed material of tooth is totally replenished. Although this cycle, is subjected to change:-

- (i) The phase of inversion might not take place, resulting in loss of bone, periodontal disease, and/or tissue ageing.
- (ii) In occasional situations, the positive imbalance may be seen, which indicates that the growth activity is underway. (16)

CHEMICAL MEDIATOR'S ROLE IN MOVEMENT OF TOOTH

1. CHEMOKINES

- Some cells experience apoptosis, whereas others die, leading to necrosis, when flow of blood is reduced on the side of pressure due to tension of the periodontal ligament. (17) Numerous osteoblasts and osteocytes in the surrounding alveolar bone also die as a result of these cell deaths. This triggers an acute inflammatory response, which leads to production of chemokines, which are proteins with small size that can also bring various progenitor and inflammatory cells from the vasculature into the extravascular area. (17)
- Monocyte chemo attractant protein-1 (MCP-1) is a chemokine which is generated during orthodontic movement that attracts the monocytes. (18)
- When monocytes leave the circulation and reach the tissue, they either become macrophages or osteoclasts. Within the initial few hours after movement of tooth, various mediators of inflammation are released.(17)

2. CYTOKINES

- Other cells' functions are modulated by these narrow range extracellular proteins. These cells are pro-inflammatory. (11)
- There are more than 50 cytokines that have been identified and these proteins can be seen at different phases of the inflammatory process. Tumor necrosis factor (TNF), interleukin-6 (IL-6), and interleukin-1 (IL-1) are among some of the “cytokines” that mediate bone remodeling process during movement of the tooth. (19)
- Macrophages, fibroblasts, osteoblasts, and endothelial cells, and are the inflammatory cells that generate cytokines.(17)

3. PROSTAGLANDINS

- Prostaglandins are generated by arachidonic acid metabolism. Dilatation of blood vessels, adherence of inflammatory cells, and permeability of blood vessels are few ways in which prostaglandins aid in inflammatory mediation. It was demonstrated by Yamasaki that, after injecting prostaglandin the number of osteoclast increased.(20)

- Inflammatory cells either generate prostaglandins by direct method or cytokines by indirect method, like tumor necrosis factor –alpha (TNF-alpha) after mechanical stimulation.(21)
- 4. Osteoclastogenesis
 - Multinucleated giant cells which are produced from hematopoietic stem cells are known as osteoclasts.(22) Osteoclast precursor cells develop into osteoclasts at the compression site. Cytokines, particularly interleukin-1 (IL-1) and tumor necrosis factor –alpha (TNF-alpha) are the cells that mediate osteoclasts. Interlukin -1R (IL-1R) stimulates it directly.(23) Indirectly, interlukin -1 (IL-1) and interlukin -6 (IL6) play a role.(24)
 - Local cells normally, attempt to deregulate osteoclast development by generating the RANKL decoy receptor, which is osteoprotegerin (OPG). (25)
 - As a result, for movement of tooth to occur, OPG levels at the site of compression should be lower. (17)

EFFECT OF DRUGS DURING TOOTH MOVEMENT

Root resorption, an undesired side effect of movement of tooth, has been shown to be minimised with the use of medications. Bisphosphonates are the most commonly used medication for this purpose, when given to rats, this medication reduces root resorption in a dose dependent manner. Furthermore, it has also been found that these medications modify the cemental surface by suppressing the production of acellular cementum, making the tooth root more vulnerable to the resorptive mechanism.(26)

CONCLUSION

In this review article, a better understanding on various factors and mechanisms which affect the movement of tooth are elaborated in which it has been explained that the major factors are chemical mediators such as prostaglandins, cytokines, etc, the periodontium also plays an important role as many changes occur in it during movement of the tooth. The rate of movement of tooth depends upon the magnitude of force applied and remodeling process of bone.

In today's world, the main goal of a dental practitioner is to upgrade the standard, stability and speed of movement of tooth during treatment. By understanding, the basic concepts of movement of tooth, we can resolve various issues during orthodontic treatment with different perspectives. Particularly, the understanding of mechanical perspective can help us in advancing the various techniques for orthodontic tooth movement. Nowadays, it is much needed, due to an increase in the number of adult patients, which require much more successful, low risk and versatile care.

BIBLIOGRAPHY

1. Sci-Hub | The Finite Element Method: a Tool to Study Orthodontic Tooth Movement | 10.1177/154405910508400506 [Internet]. [cited 2021 Dec 5]. Available from: <https://sci-hub.mkxa.top/10.1177/154405910508400506>
2. Murarka SP, Shrivastav S, Kamble R, Bidwai PS, Gosavi S, Merchant Z. Aesthetic management of missing anterior teeth in Binder Syndrome - A Case report. 2020;6.
3. Distal Molar Surgery. - Document - Gale Academic OneFile [Internet]. [cited 2021 Dec 10]. Available from: <https://go.gale.com/ps/i.do?id=GALE%7CA642265530&sid=googleScholar&v=2.1&it=r&linkaccess=abs&issn=22784748&p=AONE&sw=w&userGroupName=anon%7E50f087c0>
4. Photo Catalytic Silver Modified Orthodontic Brackets --An Innovative Method for Prevention of White Spot Lesions. - Document - Gale Academic OneFile [Internet]. [cited 2021 Dec 10]. Available from: <https://go.gale.com/ps/i.do?id=GALE%7CA637850497&sid=googleScholar&v=2.1&it=r&linkaccess=abs&issn=22784748&p=AONE&sw=w&userGroupName=anon%7Ec57130db>
5. Sci-Hub | Orthodontic tooth movement: The biology and clinical implications | 10.1016/j.kjms.2018.01.007 [Internet]. [cited 2021 Dec 4]. Available from: <https://sci-hub.hkvisa.net/10.1016/j.kjms.2018.01.007>
6. Sci-Hub | The fundamentals of tooth movement | 10.1016/j.ortho.2009.12.001 [Internet]. [cited 2021 Dec 4]. Available from: <https://sci-hub.hkvisa.net/10.1016/j.ortho.2009.12.001>
7. [The ideal forces for canine retraction]. - Abstract - Europe PMC [Internet]. [cited 2021 Dec 5]. Available from: <https://europepmc.org/article/med/2486319>
8. CiNii Articles - Force in orthodontics and its relation to tooth movement [Internet]. [cited 2021 Dec 5]. Available from: <https://ci.nii.ac.jp/naid/10006923442/>
9. Nambiar K, Kamble R, Suroliya K, Ahuja M, Daigavane P, Vora S. Alveolar Bone Grafting -A Summary of History and Current Literature on the Technique. J Evol Med Dent Sci. 2020 Sep 7;9.
10. Resistance of bonded premolars to four artificial ageing models post enamel conditioning with a novel calcium-phosphate paste [Internet]. [cited 2021 Dec 5]. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7195685/>
11. Sci-Hub | Biological aspects of orthodontic tooth movement: A review of literature | 10.1016/j.sjbs.2018.03.008 [Internet]. [cited 2021 Dec 4]. Available from: <https://sci-hub.hkvisa.net/10.1016/j.sjbs.2018.03.008>
12. Sci-Hub | Cellular, molecular, and tissue-level reactions to orthodontic force. American Journal of Orthodontics and Dentofacial Orthopedics, 129(4), 469.e1–469.e32 |

- 10.1016/j.ajodo.2005.10.007 [Internet]. [cited 2021 Dec 5]. Available from: <https://sci-hub.se/https://doi.org/10.1016/j.ajodo.2005.10.007>
13. Sci-Hub | A reconsideration of the propriety of the “pressure-tension” hypothesis | 10.1016/s0002-9416(69)90170-5 [Internet]. [cited 2021 Dec 5]. Available from: [https://sci-hub.mkxa.top/10.1016/s0002-9416\(69\)90170-5](https://sci-hub.mkxa.top/10.1016/s0002-9416(69)90170-5)
 14. Sci-Hub | The tissue, cellular, and molecular regulation of orthodontic tooth movement: 100 years after Carl Sandstedt | 10.1093/ejo/cjl001 [Internet]. [cited 2021 Dec 5]. Available from: <https://sci-hub.mkxa.top/10.1093/ejo/cjl001>
 15. Tissue changes incidental to orthodontic tooth movement - ScienceDirect [Internet]. [cited 2021 Dec 5]. Available from: <https://www.sciencedirect.com/science/article/abs/pii/S0099696332800748>
 16. Baron R. Histophysiologie des réactions tissulaires au cours du déplacement orthodontique. *Orthop Dento-Faciale Bases Fondam Paris Prelat*. 1975;328–64.
 17. Biological principles behind accelerated tooth movement - ScienceDirect [Internet]. [cited 2021 Dec 6]. Available from: <https://www.sciencedirect.com/science/article/abs/pii/S1073874615000328>
 18. Taddei SR de A, Andrade I, Queiroz-Junior CM, Garlet TP, Garlet GP, Cunha F de Q, et al. Role of CCR2 in orthodontic tooth movement. *Am J Orthod Dentofacial Orthop*. 2012 Feb 1;141(2):153-160.e1.
 19. Cytokine expression pattern in compression and tension sides of the periodontal ligament during orthodontic tooth movement in humans - Garlet - 2007 - *European Journal of Oral Sciences* - Wiley Online Library [Internet]. [cited 2021 Dec 7]. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-0722.2007.00469.x>
 20. Yamasaki K, Miura F, Suda T. Prostaglandin as a Mediator of Bone Resorption Induced by Experimental Tooth Movement in Rats. *J Dent Res*. 1980 Oct 1;59(10):1635–42.
 21. Tumor Necrosis Factor- α Promotes Sustained Cyclooxygenase-2 Expression: Attenuation by Dexamethasone and NSAIDs - ScienceDirect [Internet]. [cited 2021 Dec 7]. Available from: <https://www.sciencedirect.com/science/article/abs/pii/S0090698097001445>
 22. Modulation of Osteoclast Differentiation | *Endocrine Reviews* | Oxford Academic [Internet]. [cited 2021 Dec 7]. Available from: <https://academic.oup.com/edrv/article-abstract/13/1/66/2548658>
 23. Interleukin-1 α Activates an NF- κ B-like Factor in Osteoclast-like Cells (*) - *Journal of Biological Chemistry* [Internet]. [cited 2021 Dec 7]. Available from: [https://www.jbc.org/article/S0021-9258\(18\)82487-5/fulltext](https://www.jbc.org/article/S0021-9258(18)82487-5/fulltext)
 24. STAT3 Activation in Stromal/Osteoblastic Cells Is Required for Induction of the Receptor Activator of NF- κ B Ligand and Stimulation of Osteoclastogenesis by gp130-utilizing

Cytokines or Interleukin-1 but Not 1,25-Dihydroxyvitamin D3 or Parathyroid Hormone* - Journal of Biological Chemistry [Internet]. [cited 2021 Dec 7]. Available from: [https://www.jbc.org/article/S0021-9258\(19\)74152-0/fulltext](https://www.jbc.org/article/S0021-9258(19)74152-0/fulltext)

25. Yasuda H, Shima N, Nakagawa N, Yamaguchi K, Kinosaki M, Mochizuki S, et al. Osteoclast differentiation factor is a ligand for osteoprotegerin/osteoclastogenesis-inhibitory factor and is identical to TRANCE/RANKL. Proc Natl Acad Sci. 1998 Mar 31;95(7):3597–602.
26. Sci-Hub | The effect of drugs on orthodontic tooth movement | 10.1111/j.1601-6343.2006.00372.x [Internet]. [cited 2021 Dec 4]. Available from: <https://sci-hub.hkvisa.net/https://doi.org/10.1111/j.1601-6343.2006.00372.x>

UNDER PEER REVIEW