Accelerated Orthodontic Tooth Movement Methods: An Overview

Sunita R Melwani[1], Manish Goyal[2], Rupinder Singh Dhall[3], M K Sunil[4], Nishant Bali[5], Renuka[6]

PhD Scholar[1], Principal and HOD[2], Professor[3], Principal[4], Associate Professor[5], Assistant Professor[6]

Department of Periodontology[1], Department of Orthodontics and Dentofacial Orthopedics[2], Teerthanker Mahaveer Dental College and Research Centre, Delhi Road, Moradabad UP; Department of Prosthodontics and Crown & Bridge[3,5,6], Himachal Institute of Dental Sciences, Shimla, Himachal Pradesh; NIMS Dental College and Hospital[4], Jaipur, India

ABSTRACT:
Conventional orthodontic treatment provides well-aligned teeth that provides functionality and aesthetics boosting the confidence. In this fast-paced world, everyone wants instant outcomes even when it comes to the orthodontic treatment. Accelerated orthodontic tooth movement methods enhances tooth movement with minimal damage to the surrounding tissues. In this current review, we provide an overview of the current treatment options available for accelerated tooth movement.

KEYWORDS: accelerated orthodontic tooth movement, accelerated orthodontics, corticotomy, low-level laser therapy, piezocision

INTRODUCTION

Well aligned teeth boost the confidence and self-esteem of an individual. Orthodontic treatment has been the most accepted treatment modality for the correction of malocclusion. Fixed orthodontics usually requires 24 to 36 months depending on the severity[1].

Correspondence address: Dr. Sunita R Melwani, Department of Periodontology, Teerthanker Mahaveer Dental College and Research Centre, Moradabad, Uttar Pradesh, India.
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This prolonged time of treatment can lead to complications like white spots, dental caries, external root resorption and periodontal involvement[2,3]. Often this treatment option is refused by patients due to the extended treatment time[4]. Therefore, shortening treatment duration with certain biological agents and various procedures has been in the forefront ever since.

This paper discusses the various methods available to accelerate orthodontic tooth movement & to reduce the complications of prolonged treatment and improve patient acceptability. The various treatment options available for the orthodontist to shorten treatment time by enhancing orthodontic tooth movement can be broadly categorised into – (1) pharmacological, (2) surgical and (3) physical methods.

PHARMACOLOGICAL METHODS

Numerous molecules have been tested experimentally both in humans and animals to accelerate orthodontic tooth movement. Some of these include: prostaglandins (PGE_1 & PGE_2), corticosteroids, vitamin D_3, parathyroid hormone, thyroxine, interleukins, growth hormones, osteocalcin, nitric oxide, PRF & PRP and intravenous immunoglobulin.

Prostaglandins. These are the lipid autacoids derived from arachidonic acid. One of their most important functions is bone resorption. Prostaglandins has been reported to be biochemical mediators of bone resorption induced by orthodontic mechanical stress[5]. Repeated mucosal injections of PGs caused changes in alveolar bone morphology characterised by extensive loss of bone matrix, fibrous replacement and increased vascularity[6]. Orthodontic tooth movement itself is based on selective bone resorption and deposition around the teeth. Studies on animals and humans have shown up to 3 times faster tooth movement when compared to the control group when prostaglandins are administered[7]. The use of PGs was found to be safe not causing any changes in the periodontal tissues including root resorption. However, a few studies have shown a trend toward root resorption which was found to be dose dependant[8,9]. Seifi M et al[8] suggested the addition of calcium ions when utilizing PGs for accelerated tooth movement to stabilize the root resorption. Pain associated with the use of PGs has also been reported[6]. PGs are administered with the local anaesthetic agent, and once the effects of the LA agent wear off, the associated pain is consistent with the orthodontic tooth movement. Caglaroglu and Erdem compared the effects of submucosal and intraligamentous injection of PGE_2[10] and found the intraligamentous injection to be more effective than submucosal since it was closer to the site of tissue remodeling. However, PG injections can cause hyperalgesia due to the release of histamine, bradykinin, 5-HT, acetylcholine and substance P from nerve endings. It also needs to be delivered repeatedly owing to its short half-life.

Corticosteroids. Corticosteroids are a class of steroid hormones that are said to induce apoptosis in osteoblasts and prolong the lifespan of osteoclasts. This results in accelerated bone resorption and retardation in bone formation. They are pharmacological agents used as immunosuppressants and anti-inflammatory agents to treat pathological processes in medical and dental practice. Patients under orthodontic treatment may present variations in normal bone remodelling due to use of these agents. Limited use of corticosteroids has been found in literature for acceleration of orthodontic tooth movement. Ashcraft et al[11] conducted an experimental study on rabbits by administering corticosteroid acetate daily for 18-25 days. Even though the mean cumulative active tooth movement was 3-4 times greater than the control group they did not advocate the use of steroids as an adjunct in orthodontics. Histologically they found increased bone resorption and/or decreased bone deposition.

Vitamin D_3 . Local administration of vitamin D has shown enhanced orthodontic tooth movement[12,13]. Khalaf RM et al[14] in 2021 carried out a different study on rats to determine if a deficiency of Vitamin D had any effect on orthodontic tooth movement. The experimental group was induced with vitamin D deficiency and found that the rate of orthodontic tooth movement was not affected by induced Vitamin D deficiency. Prostaglandin and Vitamin D were compared in a study by Kale et al but no significant difference was found between the two in enhancing tooth movement[15]. They suggested that using Vitamin D would be more effective in modulating bone turnover during orthodontic tooth movement. Intraligamentary administration

of Vitamin D_3 showed 70% more tooth movement for the experimental teeth with no signs of root resorption[16].

Vitamin E. A recent study that fed rats with a Vitamin E enriched diet found an increase in orthodontic tooth movement when compared to controls fed with regular diet[17]. It was suggested that the expression of microphthalmia – associated transcription factor in alveolar bone occurred in the Vitamin E diet group.

Parathyroid hormone. This hormone is produced and secreted by the parathyroid gland. Its primary function is regulation of serum calcium concentration by exerting its effect primarily on bone as well as kidney and intestine. A drop in the body calcium level leads to bone resorption by the action of the parathyroid hormone. Parathyroid hormone promotes bone resorption mainly on the compression side by increasing osteoclastic activity[18]. The effects of parathormone and thyroxine has been so far tested on animals only and the results seem to be promising. Soma S et al[19] reported a twofold increase in orthodontic tooth movement after subcutaneous injection and suggested that continuous administration of parathyroid hormone can induce accelerated orthodontic tooth movement.

Thyroxine. The results obtained when thyroxine was employed for accelerating orthodontic tooth movement is mixed. A study by Shirazi et al in 1999 reported that the administration of L-thyroxine significantly increased the amount of orthodontic tooth movement in experimental animals[20]. They also found from SEM studies that the extent of external root resorption decreased with administration of thyroxine. Jung et al[21] however found contradictory results and stated that transmucosal administration of thyroxine could not significantly accelerate orthodontic tooth movement. Seifi et al[22] performed a study on rats where the combined use of PGE_2 and thyroxine lead to accelerated orthodontic tooth movement. They even suggested that when administered together the root resorption caused by prostaglandins could be minimised by thyroxine. A different study on hyperthyroid patients in 2010 by Seong et al found a possible correlation between the serum level of thyroid hormone and the rate of orthodontic tooth movement[23].

Interleukins. An experimental study by providing varying doses of interleukin-4 demonstrated a significant reduction in tooth movement[24]. It was concluded that interleukin-4 inhibits tooth movement and also prevented tooth resorption.

Osteocalcin. Studies[25] using osteocalcin found acceleration of orthodontic tooth movement. Osteocalcin is said to enhance osteoclastogenesis on the pressure side.

Nitrous oxide. Nomega-nitro-L-arginine methyl ester (L-NAME) was used as nitric oxide (NO) synthetase (NOS) inhibitor, and nitro-L-arginine (NLA) was used as NOS precursor in a study to evaluate the role of NO in orthodontic tooth movement[26]. Tissue sections of this study showed an increase in multinuclear osteoclasts, howships lacunae, capillary vascularization and orthodontic tooth movement in the NLA groups.

PRP – PRF.PRP and i-PRF have been used extensively in many studies[27'28] due to its easy availability and biocompatibility. All studies[27,28] carried out so far have found that platelet aggregates enhance orthodontic tooth movement. No side effects were seen on the use of these.

SURGICAL METHODS

Surgical techniques to reduce orthodontic treatment time are well documented. The cortical bone adjacent to the alveolar processes can either be cut, pierced or mechanically altered. This induces a decrease in mineral density known as osteopenia. Corticotomies enhance the acceleratory effect through the regional acceleratory phenomena (RAP). They also lead to the expression of mediators of inflammation and cytokines that increase osteoclastic activity. Corticotomies were

introduced by Kole in 1959. Due to the invasive nature, multiples of modifications have been introduced to make it more acceptable to the patient.

Periodontally accelerated osteogenic orthodontics. PAOO also called Wilckodontics (introduced by the Wilcko brothers) consists of selective corticotomy, particulate grafting and optimal orthodontic force. This innovative procedure reduced treatment time, improved the stability of teeth with minimal relapse of tooth movement[29]. It has the disadvantage of being an invasive procedure like all surgeries with post-operative pain and swelling, which have now been replaced by minimally invasive techniques.

Distracting periodontal ligament. Interseptal bone distal to the canine is undermined with a bone bur and vertical grooves inside the extraction socket along the buccal and lingual sides extending obliquely towards the socket base is performed to accommodate a tooth borne custom made intraoral distraction device[30]. It was concluded from this study that periodontal ligament can be distracted effectively with no complications

Dentoalveolar distraction. The use of a dentoalveolar distraction device is said to have reduced overall orthodontic treatment time by 50% with no unfavourable effects on the periodontium and surrounding tissues and not requiring additional extraoral/intraoral anchorage device[31].

Piezocision This is a minimally invasive surgical procedure described by Dibart et al[32] that utilizes a pizosurgical unit. Piezosurgical cuts are given in the area around the teeth to be retracted and multiple studies[33'34] have shown enhanced tooth movement.

Micro osteoperforations. These micro perforations in bone can be done with the help of a bone screw and a handheld screw driver or even a miniscrew. It is a simple method and does not require any additional expensive apparatus. Studies[35] on this have found significant increase in orthodontic tooth movement by up to2-fold. A contradictory study by Aboalnaga et al[36] in 2019 found that micro osteoperforations did not accelerate the rate of tooth movement.

PHYSICAL METHODS

According to Zengo[37], application of orthodontic forces leads to bone bending and a bioelectric potential develops. As a consequence of the bone bending theory, the concave side will be negatively charged attracting the osteoblasts while the convex side will positively charged attracting osteoclasts. Application of discontinuous forces creates the bioelectric potential. Experimental studies[38] on animals have shown a 15% to 30% acceleration in tooth movement when vibrations are applied for different durations every day.

Resonance vibration/Vibratory stimulus. Low-level mechanical oscillatory signals (vibrations) have been shown to improve bone formation and increases orthodontic tooth movement[38]. A double blind randomised trial applied vibrations to a group for 20mins/day at a frequency of 30 Hz and found that significantly higher mean rate of OTM in the intervention group[39]**.**

Low level laser therapy. Photobiostimualtion **is** one of the most extensively studied physical methods in accelerating tooth movement. LLLT accelerates tooth movement by ATP prouction and activation of cytochrome C, tooth movement is enhanced by the RANK/RANKL pathway and the macrophage colony-stimulating factor and its receptor expression. Studies[40,41] have shown it as a promising auxillary in tooth movement acceleration with no detrimental effect on surrounding tissues.

Low intensity pulsed ultrasound. Low-intensity pulsed ultrasound (LIPUS) works on the principle of mechanotransduction. Here the external acoustic waves convert fluid shear stress in biochemical changes at a cellular level. LIPUS promotes differentiation of bone-forming cells and

extracellular matrix formation by modulating growth factors and certain signalling factors. It is non-invasive, has a low level of toxicity and has highly targeted approach that makes it acceptable to the patient as an adjunct for hastening tooth movement. Studies where LIPUS has been used in conjunction with conventional orthodontic therapy have reported significant increase in orthodontic tooth movement after daily application[42]. However, a tri-weekly application did not produce any significant difference in the rate of tooth movement[43]. Root resorption after this treatment modality showed a statistically significant decrease[42]. Researches[44] have been performed wherein LLLT and LIPUS were compared and combined to determine which treatment modality enhanced orthodontic tooth movement. The combination of LLLT and LIPUS showed the best results with LLLT alone faring better than LIPUS alone.

Direct electric current & electromagnetic stimulation. Exogenous electric currents have been used both experimentally and clinically to initiate osteogenesis in intact bone. The experimental canine which had an electric appliance to provide a direct current of 20 µA 5 hours a day demonstrated 30% more tooth movement compared to their counterparts[45].

FUTURE OF ACCELERATED ORTHODONTICS

Although there are multiple approaches to enhance orthodontic tooth movement, it still remains inconclusive regarding one method's superiority over another. Patient's preference on non-invasive methods are always accepted which accelerate tooth movement. LLLT is well documented method and minimally invasive. The time and dosage of laser in LLLT is not clear and more research is needed in this direction with laser parameters defined.

CONCLUSION

Pharmacological methods enhanced orthodontic tooth movement with promising results shown by prostaglandins (PGE_1 & PGE_2), corticosteroids, vitamin D_3, parathyroid hormone, thyroxine, interleukins, growth hormones, osteocalcin, nitric oxide, PRF & PRP and intravenous immunoglobulins, but these have systemic side effects. Surgical methods are invasive and physical methods like LLLT have shown better acceptance by patients with speedy tooth movement.

REFERENCES

1. Tsichlaki A, Chin SY, Pandis N, Fleming PS. How long does treatment with fixed orthodontic appliances last? A systematic review. Am J Orthod Dentofacial Orthop. 2016;149:308–18.
2. Talic NF. Adverse effects of orthodontic treatment: a clinical perspective. Saudi Dent J. 2011;23:55–9.
3. Segal GR, Schiffman PH, Tuncay OC. Meta analysis of the treatment –related factors of external apical root resorption. Orthod Craniofac Res. 2004; 7:71-8.
4. Rosvall MD, Fields HW, Ziuchkovski J, Rosenstiel SF, Johnston WM. Attractiveness, acceptability, and value of orthodontic appliances. Am J Orthod Dentofacial Orthop. 2009;135:276-7.
5. Yamasaki K, Miura F, Suda T. Prostaglandin as a mediator of bone resorption induced by experimental tooth movement in rats. J Dent Res. 1980;59:1635-42.
6. Yamasaki K, Shibata Y, Imai S, Tani Y, Shibasaki Y, Fukuhara T. Clinical application of prostaglandin E_1 (PGE_1) upon orthodontic tooth movement. Am J Orthod. 1984;6:508-18
7. Spielmann T, Wieslander L, Hefti AF. Beschleunigung einer orthodontisch induzierten Zahnbewegung durch lokale Applikation von Prostaglandin (PGE1) [Acceleration of orthodontically induced tooth

movement through the local application of prostaglandin (PGE1)]. Schweiz Monatsschr Zahnmed. 1989;99(2):162-5. German. PMID: 2717904.
8. Seifi M, Eslami B, Saffar AS. The effect of prostaglandin E2 and calcium gluconate on orthodontic tooth movement and root resorption in rats. Eur J Orthod. 2003 Apr;25(2):199-204. doi: 10.1093/ejo/25.2.199. PMID: 12737218.
9. Sekhavat AR, Mousavizadeh K, Pakshir HR, Aslani FS. Effect of misoprostol, a prostaglandin E1 analog, on orthodontic tooth movement in rats. Am J Orthod Dentofacial Orthop. 2002 Nov;122(5):542-7. doi: 10.1067/mod.2002.126153. PMID: 12439483.
10. Cağlaroğlu M, Erdem A. Histopathologic investigation of the effects of prostaglandin E2 administered by different methods on tooth movement and bone metabolism. Korean J Orthod. 2012 Jun;42(3):118-28. doi: 10.4041/kjod.2012.42.3.118. Epub 2012 Jun 28. PMID: 23112942; PMCID: PMC3481982.
11. Ashcraft MB, Southard KA, Tolley EA. The effect of corticosteroid-induced osteoporosis on orthodontic tooth movement. Am J Orthod Dentofacial Orthop. 1992 Oct;102(4):310-9. doi: 10.1016/0889-5406(92)70046-D. PMID: 1456215.
12. Collins MK, Sinclair PM. The local use of vitamin D to increase the rate of orthodontic tooth movement. Am J Orthod Dentofacial Orthop. 1988 Oct; 94(4): 278-84. doi: 10.1016/0889-5406(88)90052-2. PMID: 3177281.
13. Kawakami M. [Effects of local application of 1, 25 (OH)2D3 on experimental tooth movement in rats]. Osaka Daigaku Shigaku Zasshi. 1990 Jun; 35(1): 128-46. Japanese. PMID: 2135402.
14. Khalaf RM, Almudhi AA. Effects of vitamin D deficiency on the rate of orthodontic tooth movement: An animal study. Saudi Dent J. 2022 Feb; 34(2): 129-135. doi: 10.1016/j.sdentj.2021.12.008. Epub 2021 Dec 23. PMID: 35241902; PMCID: PMC8864377.
15. Kale S, Kocadereli I, Atilla P, Aşan E. Comparison of the effects of 1,25 dihydroxycholecalciferol and prostaglandin E2 on orthodontic tooth movement. Am J Orthod Dentofacial Orthop. 2004 May;125(5):607-14. doi: 10.1016/j.ajodo.2003.06.002. PMID: 15127030.
16. Iosub Ciur , Zetu IN, Haba D, Viennot S, Bourgeois D, Andrian S. Evaluation of the Influence of Local Administration of Vitamin D on the Rate of Orthodontic Tooth Movement. Rev Med Chir Soc Med Nat Iasi. 2016 Jul-Sep;120(3):694-99. PMID: 30148332
17. Seong C, Chen PJ, Kalajzic Z, Mehta S, Sharma A, Nanda R, Yadav S, Dutra EH. Vitamin E enriched diet increases the rate of orthodontic tooth movement. Am J Orthod Dentofacial Orthop. 2022 May;161(5):687-697.e3. doi: 10.1016/j.ajodo.2020.10.033. Epub 2022 Jan 7. PMID: 35012806; PMCID: PMC9050852.
18. Soma S, Matsumoto S, Higuchi Y, Takano-Yamamoto T, Yamashita K, Kurisu K, Iwamoto M. Local and chronic application of PTH accelerates tooth movement in rats. J Dent Res. 2000 Sep;79(9):1717-24. doi: 10.1177/00220345000790091301. PMID: 11023269.
19. Soma, S., Iwamoto, M., Higuchi, Y. and Kurisu, K. (1999), Effects of Continuous Infusion of PTH on Experimental Tooth Movement in Rats. J Bone Miner Res, 14: 546-554. https://doi.org/10.1359/jbmr.1999.14.4.546
20. Shirazi M, Dehpour AR, Jafari F. The effect of thyroid hormone on orthodontic tooth movement in rats. J

Clin Pediatr Dent. 1999 Spring; 23(3): 259-64. PMID: 10686873.
21. Jung, Woo-Young, Seong Jin Ahn, Seung Wook Oh, Kyung-A Kim, Ki-Ho Park and Young-Guk Park. "Effects of transmucosal thyroxine administration on the tooth movement in an animal model." *APOS Trends in Orthodontics* 8 (2018): 64 - 70.
22. Seifi M, Hamedi R, Khavandegar Z. The Effect of Thyroid Hormone, Prostaglandin E2, and Calcium Gluconate on Orthodontic Tooth Movement and Root Resorption in Rats. J Dent (Shiraz). 2015 Mar; 16(1 Suppl):35-42. PMID: 26106633; PMCID: PMC4476115
23. Kim, Seong Oh & Kim, Seong-Oh & Kim, Chul & Lee, Jaeho & Son, Heung-Kyu. (2010). The effect of hyperthyroidism on the rate of orthodontic tooth movement. The journal of the korean academy of pediatric dentistry.
24. Hakami Z, Kitaura H, Kimura K, Ishida M, Sugisawa H, Ida H, Jafari S, Takano-Yamamoto T. Effect of interleukin-4 on orthodontic tooth movement and associated root resorption. Eur J Orthod. 2015 Feb; 37(1): 87-94. doi: 10.1093/ejo/cju016. Epub 2014 Jul 29. PMID: 25074244.
25. Hashimoto F, Kobayashi Y, Mataki S, Kobayashi K, Kato Y, Sakai H. Administration of osteocalcin accelerates orthodontic tooth movement induced by a closed coil spring in rats. Eur J Orthod. 2001 Oct; 23(5): 535-45. doi: 10.1093/ejo/23.5.535. PMID: 11668873.
26. Akın E, Gurton AU, Ölmez H, Effects of nitric oxide in orthodontic tooth movement in rats. American Journal of Orthodontics and Dentofacial Orthopedics Volume 126, Issue 5, 2004, Pages 608-614,
27. Zeitounlouian TS, Zeno KG, Brad BA, Haddad RA. Effect of injectable platelet-rich fibrin (i-PRF) in accelerating orthodontic tooth movement: A randomized split-mouth-controlled trial. J Orofac Orthop. 2021 Jul; 82(4): 268-277. English. doi: 10.1007/s00056-020-00275-x. Epub 2021 Jan 22. PMID: 33481053.
28. Erdur EA, Karakaslı K, Oncu E, Ozturk B, Hakkı S. Effect of injectable platelet-rich fibrin (i-PRF) on the rate of tooth movement. Angle Orthod. 2021 May 1; 91(3):285-292. doi: 10.2319/060320-508.1. PMID: 33459765; PMCID: PMC8084468.
29. Wilcko WM, Wilcko MT, Bouquot JE. Rapid orthodontics with alveolar reshaping: two case reports of decrowding. *Int J Periodontics Restorative Dent.* 2001;21:9–19
30. Liou EJ, Huang CS. Rapid canine retraction through distraction of the periodontal ligament. Am J Orthod Dentofacial Orthop. 1998 Oct; 114(4): 372-82. doi: 10.1016/s0889-5406(98)70181-7. PMID: 9790320.
31. Kurt G, Işeri H, Kişnişci R. Rapid tooth movement and orthodontic treatment using dentoalveolar distraction (DAD). Long-term (5 years) follow-up of a Class II case. Angle Orthod. 2010 May; 80(3): 597-606. doi: 10.2319/041209-209.1. PMID: 20050758; PMCID: PMC8985729.
32. Dibart S, Sebaoun JD, Surmenian J. Piezocision: a minimally invasive,periodontally accelerated orthodontic tooth movement procedure. *Compend Contin Educ Dent* 2009 30:342–344,346, 348-350
33. Abbas NH, Sabet NE, Hassan IT. Evaluation of corticotomy-facilitated orthodontics and piezocision in rapid canine retraction. Am J Orthod Dentofacial Orthop. 2016 Apr; 149(4):473-80. doi: 10.1016/j.ajodo.2015.09.029. PMID: 27021451.

34. Charavet C, Lecloux G, Bruwier A, Rompen E, Maes N, Limme M, Lambert F. Localized Piezoelectric Alveolar Decortication for Orthodontic Treatment in Adults: A Randomized Controlled Trial. J Dent Res. 2016 Aug; 95(9): 1003-9. doi: 10.1177/0022034516645066. Epub 2016 Apr 29. PMID: 27129491.
35. Kumar P, Rampurawala AH, Patil AS. Effect of micro-osteoperforations (MOPs) on the rate of en masse orthodontic tooth retraction: A randomized controlled trial. J Orofac Orthop. 2022 Aug 26. English. doi: 10.1007/s00056-022-00420-8. Epub ahead of print. PMID: 36018346.
36. Aboalnaga AA, Salah Fayed MM, El-Ashmawi NA, Soliman SA. Effect of micro-osteoperforation on the rate of canine retraction: a split-mouth randomized controlled trial. Prog Orthod. 2019 Jun 3; 20(1):21. doi: 10.1186/s40510-019-0274-0. PMID: 31155698; PMCID: PMC6545296.
37. A.N. Zengo, R.J. Pawluk, C.A.L. Bassett,Stress-induced bioelectric potentials in the dentoalveolar complex, American Journal of Orthodontics, Volume 64, Issue 1,1973,Pages 17-27,
38. Makoto Nishimura, Mirei Chiba, Toshiro Ohashi, Masaaki Sato, Yoshiyuki Shimizu, Kaoru Igarashi, Hideo Mitani, Periodontal tissue activation by vibration: Intermittent stimulation by resonance vibration accelerates experimental tooth movement in rats,American Journal of Orthodontics and Dentofacial Orthopedics, Volume 133, Issue 4,2008,Pages 572-583
39. Dubravko Pavlin, Ravikumar Anthony, Vishnu Raj, Peter T. Gakunga, Cyclic loading (vibration) accelerates tooth movement in orthodontic patients: A double-blind, randomized controlled trial,Seminars in Orthodontics,Volume 21, Issue 3,2015,Pages 187-194,
40. Gauri Doshi-Mehta, Wasundhara A. Bhad-Patil, Efficacy of low-intensity laser therapy in reducing treatment time and orthodontic pain: A clinical investigation, American Journal of Orthodontics and Dentofacial Orthopedics, Volume 141, Issue 3,2012,Pages 289-297
41. Cruz DR, Kohara EK, Ribeiro MS, Wetter NU. Effects of low-intensity laser therapy on the orthodontic movement velocity of human teeth: a preliminary study. Lasers Surg Med. 2004; 35(2): 117-20. doi: 10.1002/lsm.20076. PMID: 15334614.
42. El-Bialy T, Farouk K, Carlyle TD, Wiltshire W, Drummond R, Dumore T, Knowlton K, Tompson B. Effect of Low Intensity Pulsed Ultrasound (LIPUS) on Tooth Movement and Root Resorption: A Prospective Multi-Center Randomized Controlled Trial. J Clin Med. 2020 Mar 16;9(3):804. doi: 10.3390/jcm9030804. PMID: 32188053; PMCID: PMC7141368.
43. Qamruddin I, Alam MK, Mahroof V, Karim M, Fida M, Khamis MF, Husein A. Biostimulatory Effects of Low-Intensity Pulsed Ultrasound on Rate of Orthodontic Tooth Movement and Associated Pain, Applied at 3-Week Intervals: A Split-Mouth Study. Pain Res Manag. 2021 May 5; 2021: 6624723. doi: 10.1155/2021/6624723. PMID: 34035871; PMCID: PMC8118727.
44. Maurya RK, Singh H, Kapoor P, Jain U, Mitra R. Effects of low-level laser and low-intensity pulsed ultrasound therapy on treatment duration and pain perception. J Clin Orthod. 2019 Mar; 53(3):154-162. PMID: 31009384.
45. Kim, Justin & Park, Young & Kang, Seung-Gu. (2008). The effects of electrical current from a micro-electrical device on tooth movement. Korean Journal of Orthodontics - KOREAN J ORTHOD. 38. 10.4041/kjod.2008.38.5.337.