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(54) **ORTHODONTIC TREATMENT**

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(57) **ABSTRACT**

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Described is a bioelectric stimulating device for reducing orthodontic treatment time (braces) with post-treatment stability enhancement. The device and associated methods provide a native sustainable optimal release of an increase in the quantity of the right cells and proteins over time and in the right sequence to optimize tooth movement with the braces by accelerating bone resorption at the leading edge of the tooth during movement. This acceleration phenomenon is responsible for being able to shorten orthodontic treatment time. Following the final alignment of the teeth, the same device can utilize the native response and accelerate the tooth/bone interface stability by targeting specific cells and proteins that are responsible for bone deposition (hardening) in order to shorten the retention phase, while greatly decreasing the chance of relapse (instability).

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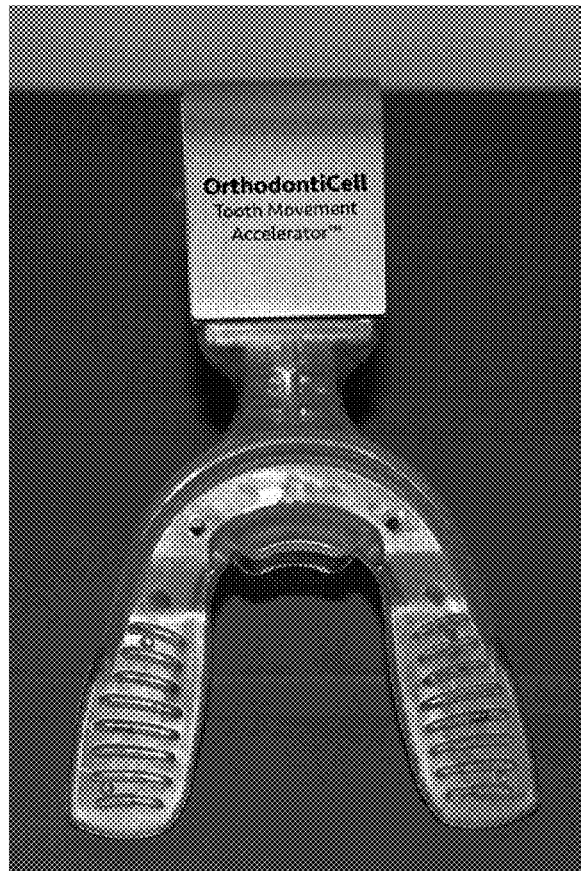
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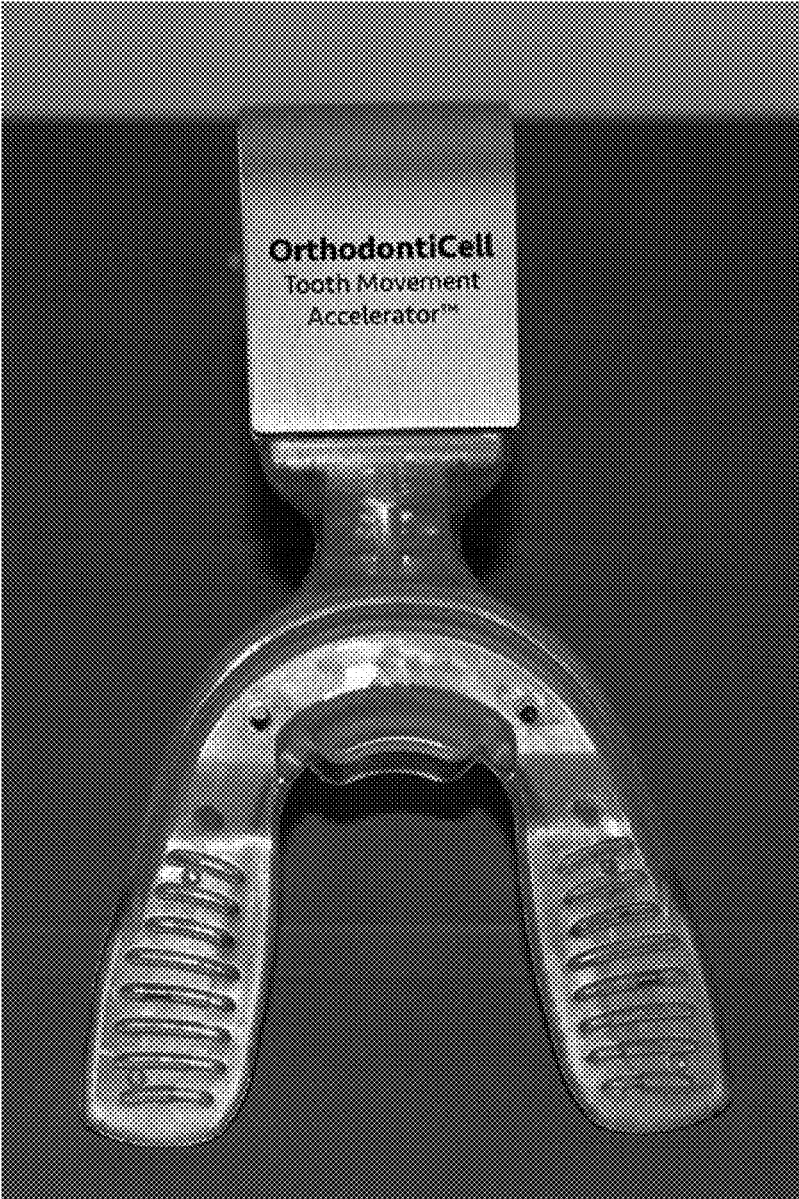
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**FIG. 1**

## ORTHODONTIC TREATMENT

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit under 35 USC §119 of U.S. Provisional Patent Application Ser. No. 62/314,240, filed Mar. 28, 2016; the disclosure of which is incorporated herein in its entirety by this reference.

### FIELD

[0002] The application relates generally to the field of dental devices and associated treatments, and more specifically to precise bioelectrical stimulation of a subject's tissue to shorten orthodontic treatment time (e.g., with braces).

### BACKGROUND

[0003] Conventional orthodontic treatment ("braces") lasts on average from 22 to 24 months due to the fact that the teeth are housed in bone that must go through the resorption/demineralization (softening) process to allow the teeth to move. The longer the treatment takes, the more side effects are possible including permanent root length loss and/or gum and bone disease due to improper patient care.

[0004] Corticotomy is a widely accepted method for accelerating tooth movement to shorten treatment time but requires costly bone and gum surgery that can be painful and has significant associated morbidity.

[0005] Following orthodontic treatment, there is a prolonged period of retention while the bone deposition (hardening) takes place over the period of up to two years (retention). Orthodontic literature places instability/relapse at 30% or greater. Currently, there is long-term retention using retainers, both fixed and removable, which requires diligence and continued cooperation.

[0006] Prior art attempts to shorten orthodontic treatment time have proven ineffective, generally due to their inability to significantly increase the rate of tooth movement. Specific protein injection systems to enhance bone resorption have experienced a lot of wash out of the therapeutic agent, so continual re-injections are needed and are thus more painful and are prone to cause infections. Laser therapy systems and vibrational energy systems have been generally ineffective as described in orthodontic literature

### BRIEF SUMMARY

[0007] Described is a system (device and method) that provides sustainable optimal protein release by a subject with an increase in the quantity of the correct cells and proteins over time and in the right sequence to optimize orthodontic tooth movement by accelerating bone resorption/demineralization at the leading edge of the tooth during movement. This acceleration phenomenon result in shortened orthodontic treatment times (e.g., the amount of time braces need to be worn by the subject).

[0008] Described is a bioelectric stem cell and protein stimulation device that reduces orthodontic treatment time by, e.g., half (or even more). The device and method provide sustainable optimal release of the cells and protein with an increase in the quantity of the ideal cells and proteins over time and in the right sequence to optimize orthodontic tooth movement by accelerating bone resorption/demineralization at the leading edge of the tooth during orthodontic movement. The bone is then re-mineralized on the trailing edge,

and then fully once the teeth are in their corrected orthodontic positions for added stability.

[0009] The described system reduces the time necessary to effect a desired tooth movement, which can reduce the pain associated with tooth movement. It also reduces the tendency of teeth to relapse to their original positions after stopping the orthodontic treatment, and ultimately reduces the time in which unsightly braces need to be worn. The bioelectric stimulator targets the exact native bone resorption pathways that are necessary for tooth movement when an orthodontic force is applied. Specific proteins activate specific cells to cause the cells to initiate bone resorption. This stimulation allows for a greater expression of the specific proteins available that can activate the increased native pluripotent cells. This in turn activates and increases the process of differentiation of pluripotent cells into osteoclasts (bone resorbing cells). With these increases in the targeted bone resorption (softening), the teeth are able to move more rapidly, resulting in an increased rate of tooth movement.

[0010] The bioelectric stimulator is also used to enhance bone stability following tooth movement utilizing the bone deposition pathway. In the same manner as described for bone resorption, specific proteins stimulate specific cells to differentiate into osteoblasts (bone deposition cells) and thereby increase the quantity and quality of bone surrounding the teeth after orthodontic tooth movement. This can be done rapidly by expressing for the right proteins and cells at the right time to cut the stability time by up to one half.

[0011] Also described is a bioelectric stimulator programmed to activate release (in a subject) of RANKL, TNFalpha, OPG, SDF-1, HGF, IGF-1, VEGF, eNOS and M-CSF.

[0012] Bone resorption/deposition is a balance between the amount of RANKL verses OPG present. When RANKL is signaled for, there is still OPG present, which counteracts some of the RANKL so it is preferred to have significant over expression of RANKL and then conversely for OPG.

[0013] Pulsed electromagnetic fields to stimulate OPG and RANKL values are generally too low to make any type of a significant difference. Kanzaki et al. (2004); Kanzaki et al. (2002).

[0014] A preferred such system includes:

[0015] A bioelectric stimulator that controls/stimulates release/production of RANKL, TNF-alpha, OPG, SDF-1, HGF, IGF-1, VEGF, eNOS and M-CSF.

[0016] The most important and most difficult to achieve bioelectric signals are the ones that control stem cell differentiation into useful tissue. The bioelectric signals are also the ones that require the most precise control by the bioelectric stimulator.

[0017] The prior art systems fail to produce the correct proteins to attract and produce the right cells in the proper sequence to facilitate consistently increased tooth movement. Existing devices fail to consistently increase the necessary cells and proteins in sequence in order to accelerate the resorption/demineralization (softening) process in bone. Therefore these devices have a limited effect on increasing the rate of tooth movement.

[0018] For instance, the prior art (e.g., Jansen et al.) did not identify the optimal signals for RANKL and OPG. Their change values were under 30%. There was no control of protein expression. They did not use direct electrical conduction contact with gums to ensure greater signal purity

delivery and superior results. There was too much drift in their signal, which in turn can cause bone formation in gums.

**[0019]** In the system hereof, the OPG signal directly stimulates osteoprogenitors towards osteogenic differentiation. The RANKL signal in the system hereof also decreases MT1-MMP expression.

**[0020]** Relating to the bioelectric stimulation-controlled release of receptor activator of NFκ-B ligand (“RANKL” or “TNFSF11”) among other proteins, including stem cell homing factor SDF-1, designed to accelerate tooth movement and cut in half the time required for orthodontic treatment with braces and clear aligners.

**[0021]** A bioelectric signal produces RANKL (Receptor activator of nuclear factor kappa-B ligand): 3 MV at 2/100 Hz alternating frequency with current of 3 ma.

**[0022]** This bioelectric signal may optionally be followed by: 15 Hz, 1 Gauss EM field, (e.g., applied at the orthodontist’s office) consisting of 5-millisecond bursts with 5-microsecond pulses followed by 200-μs pulse duration @ 30 Hz and with current amplitude of 140 mA for minimum 20 to 45 minutes. The office use supplemental extra booster electromagnetic field (Gaus signal) may be delivered wirelessly with no conduction elements in the subject’s mouth.

**[0023]** A bioelectric signal produces OPG osteoprotegerin (also known as osteoclastogenesis inhibitory factor (OCIF), or tumor necrosis factor receptor superfamily member 11B (TNFRSF11B), is a protein that in humans is encoded by the TNFRSF11B gene) by bioelectric signal range 3 my to 5 my @ frequency range 1 to 3 MHz duration range 30 to 40 mW/cm<sup>2</sup> for a minimum of 20 to 45 minutes.

**[0024]** The system addresses the desire to reduce the time it takes to treat orthodontic patients, which would be a boon to them. This approach speeds up the normal process of bone demineralization in order to accelerate tooth movement. Prior art laser light and vibration devices have generally fallen short in providing a reliable pathway to the underlying mechanism of action for tooth movement. Also, repeat RANKL needle injection methods are painful for patients and needed too frequently. The described system provides clear cut, direct control for the release of essential cells and proteins needed for accelerating tooth movement, and with less pain. Additionally, it can be used in the areas of oral surgery and periodontal surgery for bone grafts to enhance the healing phase of the procedure. Additionally, it can be utilized to enhance the speed for integration of dental implants in bone.

**[0025]** Also, the device is applicable for use in craniofacial surgery where bone grafts are used to repair facial anomalies. Oral surgery can be benefited by the use of this device for repairing bones in orthognathic surgery, jaw fracture, bone plate insertion, various grafts, and implants. All these areas can benefit from the use of the device because it reduces the amount of discomfort from any of the procedures as the stem cell recruitment lessens the subject’s pain.

#### BRIEF DESCRIPTION OF THE DRAWING

**[0026]** FIG. 1 depicts a programmed bioelectric stimulator for use with the described system.

#### DETAILED DESCRIPTION

**[0027]** The bioelectrical stimulation causes the subject’s tissues to release SDF-1, M-CSF, RANKL, OPG, VEGF, IGF-1, and TNF-alpha, eNOS in greater quantities.

**[0028]** RANKL binds to the RANK receptor on the mesenchymal precursor cells to differentiate into Osteoclasts which are responsible for bone resorption/demineralization. TNF-alpha is another pathway similar to RANKL and acts in much the same way to cause differentiation of osteoclastic precursors into Osteoclasts. VEGF will increase blood supply by forming additional blood vessels to initially carry away the minerals and mineral salts during the resorption process (demineralization), on the leading side of tooth movement, and then carry the minerals back to the areas for remineralization on the trailing side, during tooth movement. Bringing these sequences of cells and proteins together can reduce up to 300%, the amount of time needed to wear orthodontic braces to finish the teeth straightening procedure.

**[0029]** It has been shown that RANKL injections accelerated by 2/3rds tooth movement and OPG—Osteoprotegerin—injections served to freeze tooth positions after movement. Zupan et al. “The relationship between osteoclastogenic and anti-osteoclastogenic pro-inflammatory cytokines differs in human osteoporotic and osteoarthritic bone tissues,” *Journal of Biomedical Science*, 2012, 19:28 (DOI: 10.1186/1423-0127-19-28), the contents of which are incorporated herein by this reference. However, two to three time weekly needle injections need to be done by a doctor in an orthodontist’s office are not well tolerated by most patients, have risk of infection, cause pain and have a high cost.

**[0030]** The described device and method produces the same volume of RANKL protein and OPG as the needle injection studies with only two 20 minute bioelectric protein expression with 3-4 stimulation sessions a week. The stimulation is pain free in fact it reduces any pain that may be present. The stimulation can be done in the subject’s home, e.g., while watching TV or reading conveniently at a relatively low cost. There is virtually no risk of infection.

**[0031]** The device described herein provides sustainable optimal release with an increase in the quantity of the right cells and proteins over time and in the right sequence to optimize tooth movement by accelerating bone resorption/demineralization at the leading edge of the tooth during movement. This acceleration phenomenon is responsible for being able to shorten orthodontic treatment time significantly. Also, it can produce orthodontic tooth movement acceleration, orthodontic treatment tooth stabilization, and craniofacial bone graft healing acceleration and it has been shown that the teeth are able to move more rapidly, with research indicating an increased rate of up to 300%.

**[0032]** The bioelectric stimulator is also used to enhance bone stability following orthodontic tooth movement utilizing the bone deposition pathway. In the same manner as for bone resorption, the specific proteins stimulate the specific cells to differentiate into osteoblasts (bone deposition cells) and thereby increase the quantity and quality of bone surrounding the teeth after tooth movement. This can be done rapidly by expressing the right proteins and cells at the right time to cut the stability time by up to one third.

**[0033]** In certain embodiments, the method includes: placing a bioelectric stimulator having electrically associated therewith a conductive mouthpiece constructed to fit covering the teeth and against the dental gums of a subject via the conductive mouthpiece. The bioelectric stimulator is attached to and/or in electrical association with a conductive mouthpiece that fits adjacent to the respective teeth and

gums. The conductive mouthpiece is typically made of an organic polymer that conducts electricity and is sized and shaped to fit the subject's teeth (see, FIG. 1). The bioelectric stimulator sends preprogrammed signals to the gum and bone tissue, e.g., via the conductive mouthpiece, for specific cell and protein expression during active tooth movement.

**[0034]** The bioelectric stimulator and conductive mouthpiece cause SDF-1 release in the subject as a cell homing signal to recruit mesenchymal stem cells from bone marrow and dental gums to become osteoclastic precursor cells. The stimulator causes SDF-1 release as a cell homing signal to recruit mesenchymal stem cells from bone marrow and gingival tissue (gums) to become osteoclastic precursor cells.

**[0035]** The bioelectric stimulator and conductive mouthpiece cause M-CSF release in the subject as a cell homing signal to recruit osteoclastic precursor cells from bone marrow and dental gums to differentiate into osteoclasts. The M-CSF is a cell homing signal to recruit osteoclastic precursor cells from bone marrow and gingival tissue (gums) to differentiate into osteoclasts.

**[0036]** Typically, one set of signals from the bioelectric stimulator will attract the cells in SDF-1 and M-CSF to increase the numbers of osteoclastic progenitor cells to the area of tooth movement.

**[0037]** The bioelectric stimulator and conductive mouthpiece cause an increase in the level of RANKL in the subject to allow the osteoclastic precursor cells to become osteoclasts and increase the rate of bone resorption/demineralization. The increased expression level of RANKL allows the osteoclastic precursor cells to become osteoclasts and multinucleated osteoclasts and thereby increase the bone resorption process.

**[0038]** The bioelectric stimulator and conductive mouthpiece cause VEGF to increase blood vessels and blood supply in the subject to carry the necessary proteins and minerals and mineral salts needed for bone resorption/demineralization and osteosynthesis. VEGF increases blood vessel formation and blood supply to carry the necessary proteins and mineral salts needed for bone resorption (softening).

**[0039]** The bioelectric stimulator and conductive mouthpiece cause IGF-1 release in the subject, which increases the rate of bone metabolism for bone resorption/demineralization and then the re-mineralization process.

**[0040]** The bioelectric stimulator and conductive mouthpiece cause release of TNF-alpha in the subject to help osteoclast differentiation, function and survival for the process of resorption/demineralization of bone on the leading edge of tooth movement. The TNF-alpha helps to induce osteoclast differentiation, function, and survival for the process of bone resorption on the leading edge of the tooth during movement.

**[0041]** The bioelectric stimulator and conductive mouthpiece cause OPG release to enhance osteoblast formation and bone formation/re-mineralization for tooth stability following orthodontic tooth movement.

**[0042]** Relationship Between the Components:

**[0043]** The bioelectric stimulator sends specific signal(s) to the tissue for cell and protein expression typically via the conductive mouthpiece.

**[0044]** SDF-1 and M-CSF release recruits an increased number of osteoclastic progenitor cells to the area of tooth movement.

**[0045]** RANKL and TNF-alpha direct the increased number of pre-osteoclastic cells to differentiate into osteoclasts and thereby accelerates the resorption/demineralization (softening) of bone.

**[0046]** VEGF is responsible for carrying the minerals and mineral salts away during the resorption/demineralization process.

**[0047]** Another set of signals cause the over expression of TNF-alpha and RANKL, which directs the pre-osteoclastic cells to differentiate into additional osteoclasts and thereby accelerates the resorption (softening) of bone due to the increase in the number of progenitor cells with activating proteins. Historically, the rate of tooth movement is limited by the number of osteoclasts available to cause bone resorption, at the leading (compression) side of tooth movement.

**[0048]** VEGF speeds up the process of bone metabolism for the resorption/demineralization and then bone formation re-mineralization.

**[0049]** The release of eNOS nitric oxide synthase improves local blood flow.

**[0050]** eNOS and VEGF are responsible for carrying the mineral salts away during the resorption process, which allows the bone to be demineralized (softened) and the tooth to move through the bone. The more the bone resorbs, the more blood vessels are needed to carry the mineral salts away, to allow for a substantial increase in tooth movement.

**[0051]** OPG causes the bone to re-mineralize and the teeth to stabilize in their orthodontic corrected positions. The stimulator and conductive mouthpiece cause an increased release of OPG following the completion of tooth movement, to enhance tooth/bone stability by stimulating increased osteoblastic activity with additional tooth stabilizing bone deposition. This signal is utilized following orthodontic tooth movement to enhance tooth stability through an increase of bone deposition (hardening). The signal will stimulate an increase of osteoblastic activity (greater number of progenitor cells and increased expression of OPG) to strengthen the bone following the completion of tooth movement. This will substantially increase the rate of bone deposition which will lead to improved tooth/bone stability in a significantly shorter period of time.

**[0052]** By using the stimulator to increase the number of osteoclastic cells and specific proteins and by combining these effects in a sequential way, the rate of bone resorption/demineralization is increased. This will result in accelerating tooth movement and therefore a decrease in the length of time for orthodontic treatment.

**[0053]** A bioelectric signal generator (FIG. 1) is used to generate the specific signals typically transmitted via the conductive mouthpiece that cause the specific cells and proteins to be released from cells associated with the gums and bone. The stimulator is programmed with the correct signals in the proper sequence to facilitate bone resorption/demineralization (softening). In severe cases, a micro pump may also be utilized to provide a higher volume of therapeutic agents more rapidly.

**[0054]** The device and method is for the proper signaling and sequencing for recruiting stem cells, having them differentiate into osteoclasts through the release of specific proteins, and to grow additional blood vessels to achieve the acceleration of bone resorption/demineralization for the shortening of orthodontic treatment time. A further micro pump (not shown) is optional and may be used for, e.g., severe craniofacial anomaly cases.

**[0055]** By stimulating the release of the protein OPG (antagonist of RANKL), the osteoclastic bone resorption process is halted and the progenitor cells then become osteoblasts that are responsible for bone remineralization. This facilitates orthodontic stability after the tooth movement portion of treatment is completed.

**[0056]** A bioelectric stimulator is attached to a conductive mouthpiece placed in the mouth for a minimum of 20-40 minutes a day, 3 days a week. The mouthpiece portion can conduct electricity by, e.g., being made of a conductive polymer, having a conductive hydrogel included, by using a conductive tape or wrap (see below), and/or by using conductive metal elements built into the mouth piece in strategic positions (FIG. 1).

**[0057]** Various means of accomplishing electrical conductivity in the mouthpiece are known. For example, electrically conductive adhesive tape is available from 3M of Minnesota. Silicone-based Electrically Conductive Adhesive (ECA) has been developed for the Metal Wrap-Through module technology. Conductive polymers are known in the art, and could be, e.g., linear-backbone “polymer blacks” (polyacetylene, polypyrrole, and polyaniline) and their copolymers. See, also, Kaur et al. “Electrically conductive polymers and composites for biomedical applications,” *RSC Adv.*, 2015, 5, 37553-37567 DOI: 10.1039/C5RA01851J, U.S. Pat. No. 8,660,669 (Feb. 25, 2014), CA 2685161 A1 (Oct. 18, 2007), and US 20120156648 (Jun. 21, 2012), the contents of each of which are incorporated herein by this reference.

**[0058]** The bioelectric stimulator is programmed to cause the subject's cells to release SDF-1, M-CSF, RANKL, TNF-alpha, VEGF, etc. in sequence. At periodic intervals, the polarity is reversed and the voltage is dropped to trigger cell differentiation for the remineralization process.

**[0059]** Additionally, the device may be used to help with facial bone graft/reconstruction for people with craniofacial anomalies (cleft lip and palates). Additionally, it may be useful in helping to heal surgeries to the mouth and skull including various titanium type implants. Also, it can be an orthodontic tooth movement accelerator, an orthodontic treatment tooth stabilizer, and/or a craniofacial bone graft healing accelerator.

**[0060]** Generally, the system hereof involves a bioelectric stimulator that controls release of RANKL, TNF-alpha, OPG, SDF-1, HGF, IGF-1, VEGF, eNOS and M-CSF. SDF-1 is generally for recruiting stem cells and maturing blood vessels. If useful, SDF-1, IGF-1, HGF, EGF, PDGF, Activin A+B, Follistatin, Tropoelastin can also be stimulated by the bioelectric stimulator as may GDF-10, GDF-11, Neurogenin 3 and Relaxin.

**[0061]** IGF-1 is for DNA repair. VEGF grows blood vessels eNOS dilates blood vessels.

**[0062]** The micro voltage signal generator may be produced utilizing the same techniques to produce a standard heart pacemaker well known to a person of ordinary skill in the art. An exemplary microvoltage generator is available (for experimental purpose from Cal-X Stars Business Accelerator, Inc. DBA Leonhardt's Launchpads or Leonhardt Vineyards LLC DBA Leonhardt Ventures of Salt Lake City, Utah, US). The primary difference is the special electrical stimulation signals needed to control (which signals are described later herein).

**[0063]** The construction of the electric signal generators, are known in the art and can be obtained from OEM

suppliers as well as their accompanying chargers and programmers. The electric signal generators are programmed to produce specific signals to lead to specific protein expressions at precisely the right time for the procedure.

**[0064]** Referring now to FIG. 1, depicted is a bioelectrical stimulator associated with a conductive polymer mouthpiece for use with treatment. Preferably, the bioelectrical stimulator portion of the device is about the size of two quarters (and is available from QIG Greatbatch/Greatbatch, Inc. of Frisco, Tex., US) and is programmable.

**[0065]** What follows are preferred signals.

**[0066]** 20-40 minute treatment cycles 2 times a week for 4 weeks and then 3 times a week until tooth movement is completed.

**[0067]** VEGF—Blood vessel sprouting growth (“Kanno Signal”)—0.1V applied at a frequency of 50 Hz. Duration 3 minutes.

**[0068]** SDF-1—Stem cell recruiting signal (Leonhardt I Signal)—30 pulses per second with a voltage of 3.5 mV, and successively alternating currents of 700 to 1500 picoamps for one minute, and again with 700 to 1500 picoamps for one minute+stimulated with current of 0.25 mA, pulse duration of 40 pulses/s, pulse width of 100  $\mu$ s, and frequency of 100 Hz. Duration 7 minutes.

**[0069]** Stem cell proliferation signals (Leonhardt-Chachques)—15 mV and a current of 500 picoamps at 70 pulses per minute for 3 hours+20 pulses per minute, a pulse amplitude of from 2.5-6 volts, and a pulse width of from 0.2-0.7 milliseconds for 3 hours. Duration 3 minutes.

**[0070]** IGF-1 (Genovese+Leonhardt)—3 my with electric frequency of 22 Hz, and electric current of 1 mA for 15 minutes and 3 ma for 15 minutes. Duration 5 minutes.

**[0071]** RANKL/TNF Receptor activator of nuclear factor kappa-B (NF- $\kappa$ B) ligand/TNF Alpha (Genovese+Leonhardt+Marchetto)—3 MV at 2/100 Hz alternating frequency with current of 3 ma

**[0072]** > Optional use depending on application to be followed by 15 Hz, 1 Gauss EM field, consisting of 5-millisecond bursts with 5-microsecond pulses followed by 200- $\mu$ s pulse duration @ 30 Hz and with current amplitude of 140 mA. This would typically be conducted in an orthodontic office setting.

**[0073]** eNOS—Alternating high-frequency (HF) and medium-frequency signals (MF)—Symmetric, biphasic, trapezoid pulses, with 400- $\mu$ s pulse duration and 1.5/1-s ramp-up/ramp-down duration, respectively. HF consisted of 75 Hz pulses with 6 s on-21 s off for 15 minutes. MF consisted of 45 Hz pulses with 5 s on-12 s off for 15 minutes. Followed by stimulation duration set as 20 min for both 1 Hz and 20 Hz stimulations. For 1 Hz stimulation, stimulation is applied for 9 sec, followed by a 1 sec silent period, a total of 1080 stimulations for 20 min. For 20 Hz stimulation, stimulation is applied for 2 sec, followed by silent period for 28 sec, a total of 1600 stimulations for 20 min. Duration 2 minutes.

**[0074]** The invention is further described with the aid of the following illustrative Example(s).

#### Example

**[0075]** Orthodontic braces and clear aligners work by applying force to teeth in order to gradually realign them. This force causes a demineralization (softening) of the bone, which allows the tooth to move. Although the time it takes for patients to wear braces or aligners varies considerably, it

generally takes on average about 2 years. The described system (see, e.g., FIG. 1) however utilizes bioelectric energy to significantly increase the rate at which teeth move. The system is a removable and non-invasive appliance that a patient wears in his or her mouth for 20-40 minutes every 3 days.

**[0076]** The bioelectric stimulator emits small electric pulses that control expressions of RANKL, SDF-1, HGF, IGF-1, TNF-alpha and VEGF, eNOS and M-CSF and OPG as well as stem cell differentiation. Studies have been completed for all these cells and proteins individually for various applications of regeneration. Previously, studies demonstrated that regular needle injections of RANKL in the area of desired tooth movement, significantly accelerates tooth movement and therefore decreases the time needed to wear braces or aligners.

**[0077]** This bioelectric stimulator achieves much quicker orthodontic treatment results with less pain. Also, the electrical stimulation has a pain reducing affect. When compared to the well-documented tooth movement acceleration approach of using surgical corticotomies, it is faster while removing any morbidity along with eliminating the pain and suffering of surgery. The key to the increased rate is drawing an abundance of the needed cells and proteins to the site of tooth movement to accelerate the demineralization (softening) and re-mineralization (hardening) of bone, thereby allowing teeth to move faster.

**[0078]** One example is SDF-1, a key signal for homing stem cells from the surrounding tissue (bone marrow, gum tissue, fat cells and circulating blood) to come to the treated site to aide in tooth movement. There are many other cells and proteins and cytokines that have an increased expression through specific patented signals, all working to substantially increase the rate of tooth movement.

**[0079]** The described system addresses the desire to reduce (e.g., by half) the time it takes to treat orthodontic patients. The approach is to speed up the normal process of bone demineralization in order to accelerate tooth movement. This described system is completely different than previous devices as it provides clear cut direct control for the release of essential cells and proteins needed for accelerating tooth movement, and with less pain.

**[0080]** The bioelectric stimulator leads to over-expression of SDF-1, which recruits critical progenitor cells and proliferates them in the area of orthodontic tooth movement forces. Concurrently, the progenitor cells are acted upon by the proteins over-expressed via the stimulator. As the increasing number of osteoclastic progenitor cells and the increasing specific proteins combine, the net effect is an increase in the number of osteoclasts. These cells are responsible for the demineralization of the bone and are known to be the limiting factor in tooth movement. The greater number of osteoclasts, the greater the resorption/demineralization and the greater the rate of tooth movement.

**[0081]** As the bone is demineralized, there is a need to remove the mineral salts away from the area. This is achieved by signaling for enhance growth of blood vessels and improved blood flow. This increase in blood vessel growth allows the minerals that are a byproduct of bone resorption to be carried away from the site of bone resorption. As the demineralization reaches a critical amount, tooth movement will take place. The increase rate of bone resorp-

tion results in an acceleration of tooth movement and therefore a decrease in the length of time needed for orthodontic treatment.

**[0082]** Once the tooth movement is finalized, the same bioelectric stimulator is programmed to increase the amount of bone remineralization. The pathway is to have an increase of the progenitor cells signaled to the area. Specific proteins can be over expressed simultaneously to act on the progenitor cells to cause the differentiation into osteoblasts, which are responsible for bone deposition. As with the bone resorption pathway, the greater the number of osteoblastic cells the greater the bone deposition. This can result in accelerating the tooth/bone stability and therefore decrease the length of time need for retention. The greater the stability, the less chance for relapse.

**[0083]** The bioelectric stimulator accurately delivers a multitude of signals to the gums and bone. The stimulator is programmed with the correct signals in the proper sequence to facilitate initially bone resorption (softening) followed by bone deposition (remineralization).

**[0084]** The two-pronged approach first works to accelerate tooth movement. The device and method are used for proper signaling with the proper sequence for recruiting stem cells, having them differentiate into osteoclasts, by the release of certain proteins, and to grow additional blood vessels are all necessary for the acceleration of bone resorption and shortening orthodontic treatment time.

**[0085]** The second part of the approach creates greater tooth stability following active tooth movement. The device and method is then used for a different signaling, with the proper sequence for recruiting stem cells, have them differentiate into osteoblasts by the release of certain proteins, and to grow additional blood vessels are all necessary for the acceleration of bone deposition and the shortening of the orthodontic retention time.

**[0086]** The only interchangeable parts are the bioelectric stimulator and the mouthpiece which is a conductive polymer. Different stimulators can be used as well as various types of materials for the mouthpiece to deliver the signals.

**[0087]** Once orthodontic treatment commences, a bioelectric stimulator is attached to a conductive polymer mouthpiece and is placed in the mouth every third day for 20-40 minutes about every other day. The mouthpiece is designed to cover one or both of the dental arches. The stimulator is programmed to cause release of SDF-1, MCSF, RANKL, TNF-alpha and VEGF, eNOS, in sequence during the active portion of treatment. Once the active orthodontic treatment is completed, the same mouth piece is re-programmed to cause release of SDF-1, OPG, VEGF, eNOS to trigger cell differentiation for the remineralization process and enhanced accelerated tooth stability.

#### REFERENCES

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- What is claimed is:
1. A device for assisting in an orthodontic procedure in a subject, the device comprising:
    - a bioelectric stimulator for producing an electrical signal, and,
    - electrically associated therewith, an electrically conductive mouthpiece comprised of a polymer and constructed to fit over the subject's teeth and in proximity of the subject's gums.
  2. A method of assisting in an orthodontic procedure in a subject, the method comprising:
    - placing the device of claim 1 over the subject's teeth and in proximity of the dental gums of the subject via a conductive mouthpiece and applying electrical stimulation to the gums as part of an orthodontic procedure.
  3. The method according to claim 2, wherein the device causes SDF-1 release in the subject as a cell homing signal to recruit mesenchymal stem cells from the subject's bone marrow.
  4. The method according to claim 2, wherein the device causes M-CSF release as a cell homing signal to recruit osteoclastic precursor cells from the subject for differentiation into osteoclasts.
  5. The method according to claim 2, wherein the device increases the level of RANKL in the subject's gums and bone to allow osteoclastic precursor cells to become osteoclasts and increase the rate of bone resorption/demineralization.
  6. The method according to claim 2, wherein the device increases VEGF so as to increase blood vessels and blood supply in the subject to carry proteins and minerals for bone resorption/demineralization.
  7. The method according to claim 2, wherein the device causes IGF-1 release in the subject, which IGF-1 increases the rate of bone metabolism for bone resorption/demineralization and the re-mineralization process.
  8. The method according to claim 2, wherein the device causes release of TNF-alpha for osteoclast differentiation, function, and survival so as to aid the process of resorption/demineralization of bone on the leading edge of tooth movement.
  9. The method according to claim 2, wherein the devices causes OPG release to enhance osteoblast formation and bone formation/re-mineralization for tooth stability following orthodontic tooth movement.



**10.** The method according to claim **2**, wherein the bioelectric signal produces RANKL (Receptor activator of nuclear factor kappa-B ligand) 3 MV at 2/100 Hz alternating frequency with current of 3 ma.

**11.** The method according to claim **10**, further comprising:

in an office setting, applying to the subject's gums a 15 Hz, 1 Gauss EM field, consisting of 5-millisecond bursts with 5-microsecond pulses followed by 200-M $\mu$ s pulse duration at 30 Hz and with current amplitude of 140 mA for minimum 20 to 45 minutes.

**12.** The method according to claim **2**, wherein the bioelectric signal produces OPG (osteoprotegerin) by bioelectric signal range 3 my to 5 my at frequency range 1 to 3 MHz duration range 30 to 40 mW/cm<sup>2</sup> for minimum 20 to 45 minutes.

**13.** The method according to claim **2**, wherein the bioelectric signal produces RANKL stimulation for accelerated tooth movement followed afterwards by OPG expression for freezing the position of the teeth after they are in the desired position.

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