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Literature Review

Vibrational Loading Applications in Dentistry A Literature Review

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Abstract

Vibration loading has extensively studied as a non-invasive method bone stimulation in the various aspect of bony pathology and the most significant application is the vibrational loading on the fracture callus. Vibrational stimulation increases the osteogenic gene expression and increases the number of osteoblast. In Dentistry vibrational loading mainly used for the orthodontic tooth movement and implant Osseo integration the proposed vibrator device produces rapid tooth movements and there are few animal studies reported the stimulation of osteoblast cell at implant surface and promote significant osseointegration. The purpose of the literature review is to provide summery of various studies of bone stimulation, orthodontic tooth movements and implant Osseo-integration by vibrational loading.

Keywords: Vibrational Loading; Bone Stimulation; Osseo Integration; Orthodontic Tooth Movements

Introduction

Adaptive response of the bone to mechanical loading, related to stress/strain ratio has seen increased activity in the last decade, have been developed in an attempt to quantify the contribution of mechanical stimulus from daily loading to bone homeostasis via mechano-transduction [1]. The techniques that develops the mechanical stimuli are electromagnetic loading and vibrational loading on the bone. However, the electromagnetic loading is invasive procedure [2], Hence the vibrational method has been popular to develop mechanical stimuli and vibrational therapy has many clinical applications apart from bone stimulation such as in endocrinology, diabetes and obesity [3]. It promotes bone and muscle strength. The vibrational loading on orthodontics tooth movements has extensively studied with the main aim of an increasing the rate of orthodontic tooth movement by accelerating the periodontal and bony tissue modelling and remodeling process [4]. Similarly, the vibrational loading on dental implant Osseo integration was studied as stimulation of osteoblast at implant surface [5]. The purpose of the review to evaluates the method of vibrational loading on bone stimulation, orthodontic tooth movements and implant osseointegration.

Method

The electronic data was searched from the years 1990 to 2016, related to vibrator application to bone stimulation, orthodontic tooth movements and implant Osseo integration. The duplication data was removed from the search list. The articles were searched from PUB-MED, Google Scholar and Sci ELO.

For the search strategy, the following terms were used in the Descriptors in Health Sciences (DeCS): bone stimulation under vibrational loading and "informatics", with the boolean operator "AND" between each word. Indexed articles, theses, dissertations as well as end-of-graduation course manuscripts were all included, with cross-sectional as well as before and after intervention designs.

The two authors were evaluated the articles and any dispute between two authors was further evaluated by third and fourth authors

Turner C, Forwood M, Rho J, Yoshikawa T (1994) [6]: Had studied bone formation was measured in rat tibiae after 12 days of applied loading. Bending forces were applied using a four-point loading apparatus. Sham loads were applied at the same magnitudes as bending forces but the loading pads were arranged so that bending was minimized. Bending and sham loading were applied to the right tibiae of rats and the left tibiae served as contralateral controls. Loading was applied as a sine wave with a frequency of 2 Hz for 18 s (36 cycles) per day. The peak magnitude of applied load was 27,33,40,52, and 64 N. Woven bone was observed on the periosteal surface in all animals subjected to loads of 40 N or greater. The amount of new woven bone and the woven bone-forming

surface were independent of the magnitude of applied strain. Bone formation on the endocortical surface was exclusively lamellar. Lamellar bone formation was stimulated by applied bending of the tibia but not by sham loading, Examination of bulk stained sections from animals exposed to the highest applied loads showed no evidence of microcracks. Thus, micro- cracks have not been implicated as a causal factor for the observed increases in bone formation rate.

Tjandrawinata RR, Vincent VL, Hughes-Fulford M, (1997) [7]: Evaluated on the bone model, The serum-deprived mouse osteoblastic (MC3T3E1) cells were subjected to a vibrational force modeled by NASA to simulate a space shuttle launch (7.83Grms). The mRNA levels for eight genes were investigated to determine the effect of vibrational force on mRNA expression. The mRNA levels of two growth related proto oncogenes, c-fos and c-myc, were up-regulated significantly within 30 mm after vibration, whereas those of osteocalcinas well as transforming growth factor-1 were decreased significantly within 3 h after vibration. No changes were detected in the levels of f3-actin, histone H4, or cytoplasmic phospholipase A2 after vibration. No basal levels of cydooxygenase-2 expression were detected. These data may also suggest that scientists use extra ground controls that are exposed to launch forces, have these forces dampened on launched samples, or use facilities such as Bio rack that provide an on board l-G centrifuge in order to control for space shuttle launch forces.

Rosenberg N, Levy M, Francis M, (2002) [8]: Had studied the Reliable and reproducible experimental methods for studying enhancement of osteoblast proliferation and metabolic activity *in vitro* Some of the current methods used for this purpose are based on the ability of the osteoblasts to react metabolically to mechanical stimulation. This method is based on the use of a specially designed vibration device that consists of an electric shaker with horizontally mounted well plate containing cell cultures. We found that vibration at a distinct set of mechanical 2 parameters of 20 Hz frequency and peak to peak acceleration of 0.5 60.1 m/sec is optimal for cell proliferation, 2 and at 60 Hz frequency with peak to peak acceleration of 1.3 60.1 m/sec for metabolic activity.

Tanaka SM, Li J, Duncan RL, (2003) [9]: To evaluate the effects of low amplitude strains ranging in frequency from 0 to 50Hz on osteoblastic function, we seeded MC3T3-E1 cells into collagen gels and applied the following loading protocols for 3min per day for either 3 or 7 days: (1) sinusoidal strain at 3Hz, with 0–3000mstrain peak-to-peak followed by 0.33s resting time, (2) ''broad frequency vibration'' of low amplitude strain (standard deviation of 300mstrain) including frequency components from 0 to 50Hz, and (3) sinusoidal strain combined with broad frequency vibration (S þ V). The cells were harvested on day 4 or 8. s. No differences due to loading were observed in alkaline phosphatase activity and in mRNA levels of type I collagen, osteopontin, connexion 43, MMPs-1A, -3, -13. These results suggest that osteoblasts are more sensitive to low amplitude, broad frequency strain, and this kind of strain could sensitize osteoblasts to high amplitude, low frequency strain.

Attard NJ, Zarb GA in (2005) [10]: Studies had reporting on patients treated with fixed and over denture prostheses. The former included partially edentulous patients treated with single or multiunit prostheses. Within the limitations of this review, it can be concluded that these treatment protocols are predictable in the anterior mandible, irrespective of implant type, surface topography, and prosthesis design (success rates 90%-100%). Limited evidence for the edentulous maxilla (success rates 90%-100%) and the partially edentulous patient (success rates 93%-100%) are available, underscoring the need for further research. There is a need to thoroughly investigate clinical outcomes to measure the economic benefit of these protocols and the impact of treatment on a patient's quality of life. Furthermore, more accurate long- term studies reporting on treatment protocols for separate clinical situations are required to allow meaningful comparisons.

Bacabac RG, Smit TH, Van Loon JJ, (2006) [11]: Investigated the bone cell response to vibration stress at a wide frequency range (5–100 Hz). The study used NO (Nitric oxide) and prostaglandin E2 (PGE2) release, and COX-2 mRNA expression as parameters for bone cell response since these molecules regulate bone adaptation to mechanical loading. COX-2 mRNA expression increased in a frequency-dependent manner, which relates to increase NO release at high frequencies, confirming our previous results. The negatively correlated release of NO and PGE2 suggests that these signaling molecules play different roles in bone adaptation to high-frequency loading. The maximum acceleration rate is proportional to 3 (frequency/2), which is commensurate with the Stokes-Einstein relation for modeling cell nucleus motion within the cytoplasm due to vibration stress. Correlations of NO and PGE2 with the maximum acceleration rate then relate to nucleus oscillations, providing a physical basis for cellular mechanosensing of high-frequency loading, Bone cell responses to high-frequency vibration stress: does the nucleus oscillate within the cytoplasm.

Patel M, Chang K, Michelle C, (2009) [12]: Studied the direct application of LMHF mechanical loading to osteoblasts alters their cell responses, preventing decreased bone formation induced by disuse or microgravity conditions. Pre-osteoblast 2T3 cells were exposed to a disuse condition using the random positioning machine (RPM) and intervened with an LMHF mechanical load (0.1–0.4 g at 30 Hz for 10– 60 min/day). Exposure of 2T3 cells to the RPM decreased bone formation responses as determined by alkaline phosphatase (ALP) activity and mineralization even in the presence of a submaximal dose of BMP4 (20 ng/ml). y LMHF mechanical loading was

enhanced by treatment with bone morphogenic protein 4 (BMP4) and blocked by the BMP antagonist noggin, suggesting a role for BMPs in this response. These findings suggest that pre osteoblasts may directly respond to LMHF mechanical loading to induce differentiation responses. The mechanosensitive genes identified here provide potential targets for pharmaceutical treatments that may be used in combination with low level mechanical loading to better treat osteoporosis or disuse-induced bone loss.

Dumas V, Ducharne B, Perrier A, Fourier C, (2010) [14]: Studied the effects of low-magnitude, high-frequency (LMHF) mechanical stimulation on osteoblastic cells are poorly understood.). We investigated the effects of these LMHF stimulations mainly on extracellular matrix (ECM) synthesis. LMHF stimulations were applied 20 min once daily for 1, 3, or 7 days in MC3T3-E1 culture (1, 3, or 7 dLMHF). Cell number and viability were not affected after 3 or 7 dLMHF. Osteoblast response to LMHF was assessed by an increase in nitric oxide secretion, alteration of the cytoskeleton, and focal contacts type I collagen in LMHF cultures were 1.8-, 1.6-, 1.5-, and 1.7-fold higher than controls, respectively (P\0.05). In terms of protein, osteopontin levels were increased after 3 dLMHF and ECM organization was altered as shown by fibronectin topology after 7 dLMHF. After decellularization, 7 dLMHF-ECM or control ECM was reseeded with MSCs, After 5 days in multi potential medium, gene-expression changes indicated that 7 LMHF-ECM promoted the expression of osteoblast markers at the expense of adipogenic marker.

Lau E, Al-Dujaili S, Guenther (2010) [14]: Studied the osteocytes release various soluble factors (e.g. transforming growth factor-β, nitric oxide, and prostaglandins) that influence osteoblastic and osteoclastic activities Osteocytes are well evidenced to be the major mechanosensor in bone, responsible for sending signals to the effector cells (osteoblasts and osteoclasts) that carry out bone formation and resorbation applied low-magnitude (0.3 × g) vibrations to osteocyte-like MLO-Y4 cells at various frequencies (30, 60, 90 Hz) for 1 h. We found that osteocytes were sensitive to this vibration stimulus at the transcriptional level: COX-2 maximally increased by 344% at 90 Hz, while RANKL decreased most significantly (−55%, $p < 0.01$) at 60 Hz. Conditioned medium collected from the vibrated MLO-Y4 cells attenuated the formation of large osteoclasts (≥ 10 nuclei) by 36% ($p < 0.05$) and the amount of osteoclastic resorbation by 20% ($p = 0.07$). It concludes that osteocytes are able to sense LMHF vibration and respond by producing soluble factors that inhibit osteoclast formation.

Hou WW, Zhu ZL, Zhou Y, Zhang CX, (2011) [15] : The study conducted on the Low-magnitude vibration has been widely used as a tool for rehabilitation, enhancing physical performance, and stimulating bone development. Although mechanical stimulation generated by vibrations is regarded as important factor in bone remodeling, the underlying cellular and molecular regulatory mechanisms of this response, which may be important in the development of new mechanobiological strategies, currently remain unclear. The results revealed that protein expression of Wnt10B and OPG was increased in a magnitude-dependent manner by mechanical vibrations at amplitudes of 0.06, 0.14, 0.32, and 0.49 9 g; the maximum increases were 2.4fold (p\0.001) and 7.9-fold (p\0.001), respectively, at 0.49 9 g. The findings may indicate that Want signaling is involved in mechanotransduction at low-magnitude vibration; this may provide a cellular basis, and impetus for further development of, biomechanically based intervention for enhancing bone strength and accelerating implant Osseo integration.

Miles, Peter S, Heath W, Robert, (2012) [16]: To assess the rate of tooth movement and discomfort experienced by orthodontic patients using a vibrational appliance (Tooth Masseuse) The experimental group showed a 65% reduction in irregularity at 10 weeks, while the control group showed a 69% reduction in irregularity over the same period. No significant differences in irregularity or pain levels were observed at any of the time points between the groups. The results demonstrate that, for 20 minute use per day, there appears to be no clinical advantage in using the vibrational.

Uzer G, Manske SL, Chan ME, (2012) [17]: The study conducted quantified vibration-induced fluid shear stresses *in vitro* and tested whether this system allows for the separation of two mechanical parameters previously proposed to drive the cellular response to vibration—fluid shear and peak accelerations. When peak accelerations of the oscillatory horizontal motions were set at 1 g and 60 Hz, peak fluid shear stresses acting on the cell layer reached 0.5 Pa. A 3.5-fold increase in fluid viscosity increased peak fluid shear stresses 2.6-fold while doubling fluid volume in the well caused a 2-fold decrease in fluid shear. Fluid shear was positively related to peak acceleration magnitude and inversely related to vibration frequency. These data demonstrated that peak shear stress can be effectively separated from peak acceleration by controlling specific levels of vibration frequency, acceleration, and/or fluid viscosity. As an example for exploiting these relations, tested the relevance of shear stress in promoting COX-2 expression in osteoblast like cells. Across different vibration frequencies and fluid viscosities, neither the level of generated fluid shear nor the frequency of the signal were able to consistently account for differences in the relative increase in COX-2 expression between groups, emphasizing that other variables including out-of-phase accelerations of the nucleus may play a role in the cellular response to vibrations.

Uzer G, Pongkitwitoon S, Chan ME, (2013) [18]: Described in vitro model in which candidate parameters including acceleration magnitude and fluid shear can be controlled independently during

vibrations. Adipose derived human MSCs (mesenchyme stem cells) were subjected to vibration frequencies and acceleration magnitudes that induced fluid shear stress ranging from 0.04 Pa to 5 Pa. Vibrations were applied at magnitudes of 0.15g, 1g, and 2g using frequencies of both 100 Hz and 30 Hz. After 14 d and under low fluid shear conditions associated with 100 Hz oscillations, mineralization was greater in all vibrated groups than in controls. Greater levels of fluid shear produced by 30 Hz vibrations enhanced mineralization only in the 2g group. Over 3 d, vibrations led to the greatest increase in total cell number with the frequency/acceleration combination that induced the smallest level of fluid shear. These data demonstrate that fluid shear does not regulate vibration induced proliferation and mineralization and that cytoskeletal remodeling activity may play a role in MSC mechano sensitivity.

Ogawa T, Vandamme K, Zhang X, Naert I, in (2014) [19]: The study was conducted on the Low-magnitude high-frequency loading, applied by means of whole body vibration (WBV), affects the bone. The rats were divided into 1 control group (no loading) and 5 test groups with low (L), medium (M) or high (H) frequency ranges and accelerations [12–30 Hz at 0.39g (FLAH); 70 - 90 Hz at 0.0759g (FMAM); 70 - 90 Hz at 0.39g (FMAH); 130 - 150 Hz at 0.0439g (FHAL); 130 - 150 Hz at 0.39g (FHAH)]. WBV was applied for 1 or 4 weeks. Implant Osseo integration was evaluated by quantitative histology (bone-to-implant contact (BIC) and peri-implant bone formation (BV/TV)). The highest BICs were found for loading regimes at high acceleration with medium or high frequency (FMAH and FHAH), and significantly differing from FLAH and FMAM (p\0.02 and p\0.005 respectively). The findings reveal the potential of high frequency vibration loading to accelerate and enhance implant Osseo integration, in particular when applied at high acceleration.

Liang Y, Meng-Chun Q, Jiang X., *et al.* in (2014) [20]: Described the effect of LMFH vibration loading as whole body vibration (WBV) on osteoporotic rats by inserting the implant into the rat tibia. The LMHF loading by WBV was performed in osteoporotic rats, with a loading duration of 4 weeks during the early stages of bone healing. The results indicated that 4-week LMHF loading by WBV partly reversed the negative effects of osteoporosis and accelerated early peri-implant Osseo integration in ovariectomized rats.

Beck BR in (2015) [21]: The studied had the evidence accumulated to suggest that whole-body vibration (WBV) may have a therapeutic role to play in the prevention of osteoporotic fracture, particularly for individuals who are unable to tolerate vigorous exercise interventions. There is moderate to strong evidence that WBV will prevent falls (likely due to enhanced neuromuscular function), but also some indication that the effects of WBV do not outstrip those of targeted exercise, Human trials, however, have produced equivocal outcomes for bone. Positive trends are apparent at the hip and spine, but shortcomings in study designs have limited statistical power. The mechanism of the vibration effect on bone tissue is likely to be mechanical coupling between an oscillating cell nucleus and the cytoskeleton. More robust dose-response human data are required before therapeutic guidelines can be developed.

OtaT, Chiba M, Hayashi H. in (2016) [22]: Conducted the study of vibrational stimulation that induces the osteoblast differentiation and the up regulation of osteogenic gene expression *in vitro*. This an experimental on vital cell by application low magnitude high frequency (LMHF) vibration loading. The osteoblast differentiation was recorded by using the spectrophotometers. The result of the study reported that under LMHF vibration loading of 1.0 - 1o m/s2 accerlation and frequencies of 30, 60 and 90 Hz respectively, there was increases in the Vibrational stimulation also significantly up regulated expression of the osteogenic marker genes Runx2, Osterix, type I collagen, and ALP. In conclusion, we developed a new vibration loading system that can precisely regulate frequency and acceleration, and the established the presence of dynamic cellular strain on a culture surface. Our findings suggest that vibrational stimulation may directly induce osteoblast differentiation.

Conclusion

The vibrational loading with variable frequency and magnitude can be successfully used for bone stimulation in orthodontia for rapid tooth movements and since, the osteoblast cell is sensitive to vibrational loading, hence the application of vibrational loading with controlled frequencies and magnitude may be beneficial for early osseointegration in implant restorations.

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