Review Article

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VIRTUES OF PULSED ELECTRO MAGNETIC FIELD TREATMENT: FUTURE AVENUES & RESEARCH TRENDS FOR ORAL SURGERY

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ABSTRACT:

Pulsed electromagnetic fields (PEMF) are increasingly acknowledged in oral surgery for their potential to enhance bone healing and mitigate postoperative complications. PEMF accelerates bone formation through heightened osteoblastic activity and enhanced expression of critical growth factors, while also demonstrating potential in reducing pain and inflammation to enhance patient recovery and comfort following surgery. Despite encouraging results, the integration of PEMF into routine oral surgical practice requires standardized protocols and comprehensive long-term safety evaluations. This article offers a comprehensive overview of existing research on PEMF's mechanisms of action and its uses in dental implantology, bone grafting, and temporomandibular joint disorders, while also discussing future directions for effective incorporation of PEMF therapy.

Key words: Pulsed Electromagnetic Field Therapy, Dental Implants, Osseointegration, Pain control, Wound healing

INTRODUCTION:

Electromagnetic field, a property of space caused by the motion of an electric charge. A stationary charge will produce only an electric field in the surrounding space. If the charge is moving, a magnetic field is also produced.[1] Pulsed Electromagnetic Field Therapy (PEMF) is a non-invasive treatment option that accelerates bone healing and promotes recovery in cases of delayed bone fracture by promoting local blood flow and increased cellular activity. PEMF therapy, also known as low field magnetic stimulation uses electromagnetic fields to potentially heal non-union fractures and depression.[2] Despite Food & Drug Administration clearance in 2007, evidence supporting the benefits of electromagnetic field devices for fractures remains inconclusive, restricting their inclusion in clinical practice guidelines for bone and

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osteochondral defects. However, electromagnetic field treatment shows potential in promoting the synthesis of skeletal extracellular matrix in response to PEMF, thereby facilitating wound healing through the production of structural and signaling molecules by skeletal cells. [3] Surgical extraction of the mandibular third molar can result in postoperative complications such as edema, inflammation, and functional limitations in mouth opening and closing movements, notably persistent pain. According to Bailey et al., pain and anxiety generated by surgery are defined as "an unpleasant emotional and sensory experience associated with actual or potential tissue damage or described in terms of such damage." [4] Effective postoperative pain management is crucial for improving quality of life and facilitating faster recovery, especially following procedures like third-molar surgery where 80% of patients report moderate to severe pain. PEMF therapy, a form of noninvasive and nonthermal treatment, modulates electromagnetic pulses to enhance cellular metabolism and promote healing. [5] It penetrates various tissues and facilitates biological responses: endothelial cells repair blood vessels, fibroblasts regenerate extracellular matrix, and muscle, cartilage, and bone cells proliferate for efficient tissue repair. PEMF therapy offers promise as a complement to analgesics, potentially reducing drug reliance and minimizing side effects in multimodal pain management. Efforts continue to find effective, side-effect-free methods for postoperative pain control amid widespread drug use. [6] Multimodal analgesia customizes treatment for individual patients, optimizing postoperative pain management and benefiting patients, healthcare providers, and society. It lowers interleukin levels to lessen inflammatory cell activity and enhances macrophage activation for clearing microorganisms and debris. This holistic approach promotes healing by alleviating initial pain and swelling, and by fostering tissue regeneration and restructuring. Unlike pharmacokinetics-dependent analgesics, PEMF's anti-inflammatory and anti-edema effects are broadly distributed across injured tissues and also support bone healing, aiding in functional recovery. [7] Dental implants rely on osseointegration for successful integration, involving blood clot formation, tissue development, and bone transition. PEMF devices use pulsed electromagnetic fields to aid tissue healing and reduce inflammation safely, advancing from older diathermy technologies to sophisticated designs. PEMF promotes bone healing and enhances osteoblast activity across various implant textures (Flat, Micro, Nano), supporting protein adsorption, osteoblast adhesion, proliferation, and differentiation via gene expression modulation.[8] These advantages underscore PEMF as a valuable asset in orthopedic and dental practices for enhancing implant osseointegration and expediting bone wound healing. PEMF therapy presents a promising avenue in the realm of oral surgery, particularly in enhancing bone healing and alleviating postoperative complications. [9] The literature reviewed underscores PEMF's ability to accelerate bone formation by stimulating osteoblastic activity and promoting the expression of crucial growth factors involved in bone regeneration. [10] Additionally, PEMF has demonstrated efficacy in reducing pain and inflammation, thereby improving patient comfort and recovery outcomes following oral surgical procedures. However, the integration of PEMF into routine clinical practice necessitates further refinement of treatment protocols and comprehensive assessment of long-term safety profiles. Variability in study parameters underscores the need for standardized approaches, facilitated by collaborative efforts across disciplines in rigorous clinical trials. Moving forward, continued research efforts are crucial to establish clear guidelines for PEMF application in different oral surgical contexts, including dental implantology, bone grafting procedures, and management of temporomandibular joint disorders. By addressing these challenges, PEMF has the potential to enhance therapeutic outcomes and redefine the landscape of oral surgical care. [11]

DISCUSSION:

PEMF treatment holds considerable promise and opens potential future pathways in oral surgery, with ongoing research focusing on several critical areas. These include enhanced bone healing, where PEMF has proven effective in improving bone regeneration around dental implants and treating bone defects. [12] Future studies aim to optimize PEMF parameters such as frequency, intensity, and duration to further enhance osseointegration rates and shorten healing times in oral implantology. [13] Another key focus is on reducing inflammation; PEMF's ability to modulate inflammatory cytokines and promote tissue repair makes it valuable for managing post-operative inflammation in oral surgeries. [14] Research efforts are directed towards exploring its potential in alleviating pain and reducing swelling following procedures such as tooth extractions and jaw surgeries. [15] Furthermore, PEMF is increasingly investigated for its ability to facilitate tissue regeneration, particularly in soft tissues such as gums and oral mucosa. It enhances fibroblasts, epithelial cells, and collagen synthesis, promising advancements in periodontal disease treatment and speeding up healing of oral mucosa. [16]

Future research may explore combining PEMF with growth factors or biomaterials to enhance regenerative outcomes, benefiting complex oral reconstructions and bone graft procedures. [17] Portable PEMF devices could extend care beyond clinical settings, facilitating advanced healing at home post-surgery. Ensuring long-term safety, including potential electromagnetic interference with dental implants, is crucial for broader clinical adoption. Tailored approaches considering age and health status could optimize the efficacy of PEMF therapy. Addressing inflammation remains pivotal, given its role in dental conditions and post-operative recovery. [18] Future studies should delve into how PEMF therapy effectively mitigates inflammation in various oral health contexts, thereby augmenting its therapeutic potential. [19] PEMF has demonstrated notable anti-inflammatory effects that could expedite recovery processes, alongside its pivotal role in stimulating cellular repair mechanisms crucial for managing oral lesions and post-surgical scenarios. Moreover, emerging evidence suggesting PEMF's antimicrobial properties highlights its potential role in oral infection management. Importantly, PEMF therapy is generally non-invasive and safe when administered within recommended guidelines, rendering it suitable for a broad spectrum of dental patients. These attributes underscore PEMF's promise as a valuable adjunctive therapy in oral health care, warranting further investigation and integration into clinical practice. [20] Electromagnetic and magnetic fields are proposed to enhance tissue healing and regeneration, particularly in promoting osteogenesis. [21] Studies in orthopedic and dental applications have shown their efficacy in enhancing bone healing and implant osseointegration. [22] Modern society is inundated with electromagnetic fields originating from power lines, household appliances, and wireless technologies. Osseointegration of dental implants hinges on establishing a robust functional and structural bond between living bone and the implant surface under load. Critical factors influencing this process encompass surgical technique, bone quality and quantity, smoking habits, implant material and surface characteristics, and the presence of postoperative infections and inflammation. Innovations introduced since the early 1990s, including topographical and chemical modifications of implant surfaces, have significantly advanced clinical outcomes compared to older, unmodified machined surfaces, thereby expanding the scope of dental implant applications. [23] The World Health Organization initiated the International Electro Magnetic Field Project in 1996 in collaboration with the International Commission on Non-Ionizing Radiation Protection to establish safe exposure guidelines. Food and Drug Administration approved medical applications of magnetic fields, regulated by the Center for Devices and Radiological Health; encompass Static Magnetic Fields generated by permanent magnets or electric currents. [24] This review examines the impact of magnetic stimulation, particularly PEMF, on enhancing healing and tissue integration in dental implant osseointegration, drawing primarily from in vitro and animal model studies, with clinical evidence showing variability. This review aims to comprehensively outline the effects of magnetic field stimulation on dental implant osseointegration, highlighting gaps in current literature and proposing future research directions. [25] It addresses the critical issue of improving patient comfort and functional outcomes by accelerating bone integration post-implant insertion. Clinicians and researchers in dentistry are increasingly focused on enhancing the speed and quality of osseointegration to facilitate quicker healing and early patient rehabilitation. [26] Dental implants typically exhibit high survival rates exceeding 90% over a decade, contingent upon the quantity and quality of available bone for insertion. [27] Implants lacking sufficient primary stability may require extended osseointegration periods or risk failure, heavily influenced by implant design characteristics and the recipient's bone quality and quantity. Surface properties of titanium and its alloys, including macro geometry and micro characteristics, significantly impact initial implant stability, which has been substantially improved through enhanced design and various surface treatments. [28] Enhancements in surgical and prosthetic techniques improve primary implant stability, yet achieving faster osseointegration remains a challenge. Noninvasive methods like pulsating electromagnetic field therapy, low-intensity pulsed ultrasound, and low-level laser therapy stimulate bone regeneration and are hypothesized to enhance implant osseointegration. However, defining optimal treatment protocols, including magnetic field intensity, frequency, and duration for PEMF stimulation, requires further research to establish standardized practices. [29] This review explores PEMFs' effects on bone cell response to biomaterials, aiming to enhance bone-implant union through biophysical stimulation, crucial for improving implant osseointegration in deficient and osteoporotic bone. [30] PEMF, a noninvasive form of low field magnetic stimulation, accelerates osseointegration by affecting osteoblasts and bone metabolism, promoting tissue integration of implants. [31] Defining optimal PEMF treatment protocol magnetic field intensity, frequency, and duration remains a challenge, necessitating further research to establish standardized practices for clinical success. [32] This review includes studies investigating PEMF effects on bone cell responses to various biomaterials, in vivo and in vitro, aiming to guide researchers and clinicians in enhancing implant osseointegration in deficient and osteoporotic bone. [33] Dental implants typically take 3 to 6 months to integrate with surrounding bone, often causing discomfort and functional limitations. Clinicians and researchers are actively seeking ways to speed up this osseointegration process, crucial for successful oral rehabilitation. With a survival rate exceeding 90% over ten years, implant success hinges on the quality and quantity of available bone. [34] Implants lacking initial stability may require extended integration periods or risk failure, influenced by factors such as design, bone quality, and enhancements to titanium alloy surfaces.

Noninvasive therapies like PEMF, low-intensity pulsed ultrasound, and low-level laser therapy stimulate bone regeneration, potentially improving osseointegration. [35] PEMF, FDA-approved since 1979, accelerates bone healing by harnessing natural electrical currents, adhering to Wolff's law, and reducing pain, swelling, and promoting faster tissue recovery. [36] Studies highlight its osteogenic effects: Jansen et al. (2010) demonstrated PEMF enhances mineralization of human bone marrow-derived stromal cells, supporting its potential for stimulating fracture healing. [37] Tabrah et al. (1990) observed PEMF's positive impact on bone mineral density in osteoporotic women, with significant localized increases during treatment. [38] Fassina et al. (2008) stimulated Saos-2 osteoblastic cells on titanium scaffolds with PEMFs, increasing expression of TGF and bone matrix proteins. [39] Atalay et al. (2013) found PEMF enhances osteoblast proliferation and activity more on pure titanium than titanium-zirconium alloy surfaces. [40] Wang et al. (2014) cultured rat osteoblasts on titanium under PEMF, enhancing protein adsorption, osteoblast functions, and upregulating osteogenesis-related genes. [41] Jing et al. (2016) stimulated MC3T3-E1 cells on porous titanium scaffolds with PEMF (15 Hertz, 2 milli Tesla) for 2 hours/day for 3 days, increasing cell proliferation, osteogenic markers, and Wnt signaling components. [42] Bloise et al. (2018) examined daily PEMF exposure on human Bone Marrow-derived Mesenchymal Stem Cells on nanostructured $TiO2$, enhancing osteogenic differentiation, Alkaline Phosphotase activity, and osteogenic gene expression. [43] These studies collectively show PEMF enhances bone healing, osteoblast activity, and osteogenic gene expression on titanium surfaces, suggesting its potential in improving osseointegration and bone tissue engineering.[44]PEMF therapy in oral surgery accelerates bone healing and regeneration, stimulates osteoblast activity, and reduces post-operative pain and inflammation. It promotes wound healing through angiogenesis, improved tissue oxygenation, and increased collagen synthesis. PEMF also decreases swelling and may enhance antibiotic effectiveness by improving local circulation and immune response. Its non-invasive nature and good tolerability make it an attractive adjunctive therapy in oral surgery, though clear guidelines and protocols from further clinical studies are needed. Optimizing PEMF treatment parameters, such as magnetic field strength, frequency, and duration, remains a challenge. [45] Research aims to refine these protocols to enhance dental implant osseointegration, crucial for improving patient rehabilitation and implant success rates exceeding 90% over a decade. [46] Design characteristics and bone health significantly impact implant stability, crucial for successful osseointegration. Advancements in implant surface properties, including titanium alloys and surface treatments, improve initial stability, facilitating quicker and more reliable integration. These innovations aim to reduce patient discomfort and enhance early functional recovery post-implantation. Alongside refined surgical techniques and prosthetic principles, they enhance primary implant stability. However, scenarios exist where faster and greater implant osseointegration is needed. Noninvasive adjunctive therapies like pulsating electromagnetic field therapy, low-intensity pulsed ultrasound, and low-level laser therapy can stimulate the body's inherent potential for bone regeneration. These methods of biophysical stimulation of bone union were developed initially to enhance the healing of fractures, healing of bone nonunions and have been hypothesized to improve implant osseointegration. A broad range of settings that includes magnetic field intensity, frequency, signals and duration of application, etc. used for PEMFs stimulation still represents a hurdle to better define treatment protocols and extensive research is needed to overcome this issue. [47]This review examines how PEMFs influence bones cell responses to various biomaterials in both in vivo and in vitro settings. [48] It focuses on enhancing bone-implant union through biophysical stimulation and aims to guide researchers and clinicians in utilizing these strategies to enhance implant osseointegration, particularly in deficient and osteoporotic bone. [49] PEMF, FDA-approved since 1979, utilizes low field magnetic stimulation to accelerate bone healing, reduce postoperative pain, and decrease tissue swelling. [50] Early studies conducted by Bassett et al. in 1964 pioneered the use of implanted electrodes to deliver direct current for promoting bone formation. Their research, primarily focused on dog femurs, observed increased bone growth specifically around the cathodes. [51] This groundbreaking work laid the foundation for exploring electrical stimulation as a means to enhance bone healing. In more recent research, PEMFs have emerged as a non-invasive alternative to direct electrical currents. [52] Studies, such as those by Jing et al. in 2016, have demonstrated that PEMFs can significantly enhance various aspects of bone physiology. [53] For instance, on titanium scaffolds, PEMFs were found to promote cell proliferation, up-regulate markers specific to osteoblasts, and activate the Wnt signaling pathway. These effects are crucial for stimulating bone growth and integration, particularly in orthopedic and dental applications where titanium implants are commonly used. [54] Moreover, studies involving animal models, including research by Spadaro et al. (1990), Akca et al. (2007), and Barak et al. (2016), have shown that PEMFs can improve bone formation around implants. [55] This evidence underscores the potential of PEMF therapy to enhance bone consolidation and implant stability, suggesting it could be a valuable adjunct in clinical settings for procedures like dental implants and bone grafts. [56] These studies underscore how electromagnetic fields influence bone physiology and healing. PEMF therapy shows promise for enhancing bone consolidation and implant stability, despite variable outcomes requiring further clinical optimization. [57] Crucial for procedures like dental implants and bone grafts, PEMF promotes optimal bone growth and integration non-invasively. It reduces pain, inflammation, and enhances tissue repair, accelerating wound healing after extractions or periodontal surgeries.

PEMF also improves post-surgery outcomes by enhancing lymphatic drainage and reducing inflammatory cytokines, potentially minimizing antibiotic use. In oral surgery, PEMF aids safe recovery and enhances natural healing processes, potentially reducing patient visits and costs. PEMF therapy exhibits a dose-response relationship, meaning the biological effects of PEMF vary depending on the intensity of the magnetic field applied. [58] Food and Drug Administration approved waveforms typically used include quasi-square/rectangular and trapezoidal shapes, while the intensities range between 0.2 to 2 millitesla , with frequencies kept below 100 Hertz. [59] Gujjalapudi et al. and Nayak et al. found continuous 0.5 milli Tesla PEMF over 12-15 hours daily enhances dental implant stability and accelerates healing. Further research is needed to refine clinical protocols. [60] PEMF stimulates chondrogenic differentiation and endochondral ossification via the Wnt/β-catenin pathway, improving trabecular microarchitecture, bone density, and strength, while also supporting chondrocyte-to-ECM balance, enhancing cartilage macromolecule expression, and promoting cell differentiation without affecting DNA or thymidine incorporation. Moreover, PEMF increases TGF-β levels, facilitating swift progression to bone formation. [61]

Future Avenues & Research Trends: Research is currently focused on optimizing PEMF treatment protocols by determining the optimal parameters of intensity, frequency, and duration for different dental applications to maximize efficacy. More randomized controlled trials are needed to establish clear evidence for the effectiveness of PEMF in various dental conditions. As evidence accumulates, PEMF has the potential to become a standard adjunctive therapy in dental clinics, particularly for procedures involving bone and tissue healing, as well as pain management. Investigating the synergistic effects of PEMF with other treatments such as antibiotics, analgesics, or regenerative materials could lead to enhanced outcomes.

Future research should prioritize patient-reported outcomes, including pain relief, satisfaction, and improvements in quality of life following PEMF treatment. Further exploring PEMF's cellular and molecular mechanisms in dental tissues could unveil new therapeutic targets. Continued research on PEMF therapy's long-term effects and safety in dental settings is crucial for broader adoption, despite promising initial results in inducing capillary growth and reducing postoperative swelling, its clinical efficacy requires scientific validation. [61]

CONCLUSION:

While PEMF treatment shows promising outcomes in research, further development and standardization of treatment protocols are needed. Variations in study conditions such as animal species, implantation sites, biomaterials, and parameters like intensity, frequency, waveform, and duration contribute to diverse observations. Collaborative efforts involving engineers, biophysicists, biologists, and medical practitioners in multicenter trials are essential to refine PEMF applications for various treatments. Well-controlled randomized clinical studies are necessary to confirm efficacy and establish optimal protocols. PEMF demonstrates potential as an effective adjunct to standard therapy for reducing post-operative swelling and pain in orthognathic surgery, suggesting routine use to enhance recovery and minimize analgesic consumption.

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