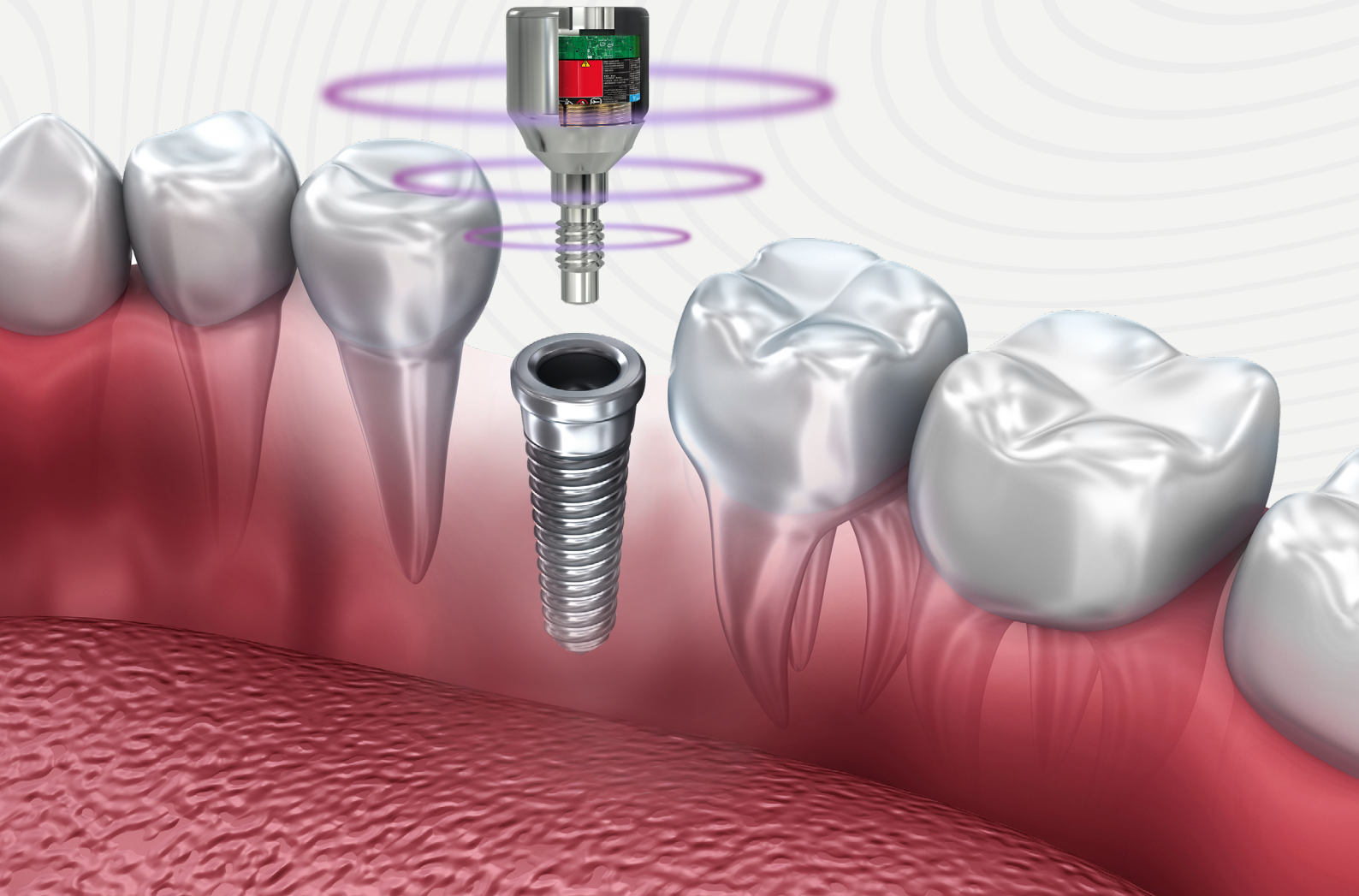
Magdent
Active Healing

Accelerating osseointegration in dental implants using pulsed electromagnetic field (PEMF) technology: **clinical rationale for Magdent MED**



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1. Executive summary

This white paper consolidates and summarizes clinical and preclinical evidence evaluating the use of localized pulsed electromagnetic field (PEMF) stimulation delivered via Magdent's Miniaturized Electromagnetic Device (MED) healing abutment. It synthesizes findings from multiple peer-reviewed studies, including a randomized controlled clinical trial, an independent human implant stability study, and a preclinical micro-computed tomography and histological investigation, with the aim of providing clinicians a single, accessible overview of the evidence.

Across these studies, MED therapy consistently demonstrates a more favorable early implant healing trajectory compared with conventional healing abutments. Reported outcomes include elimination of the typical early stability dip, significantly higher implant stability quotient values during the first weeks of healing, modulation of early inflammatory activity, and accelerated peri-implant bone formation with increased bone-to-implant contact. Delivered through a workflow-compatible healing abutment that requires no changes to standard surgical or restorative protocols, MED enables active biological support of osseointegration during the most critical and least predictable phase of implant integration.

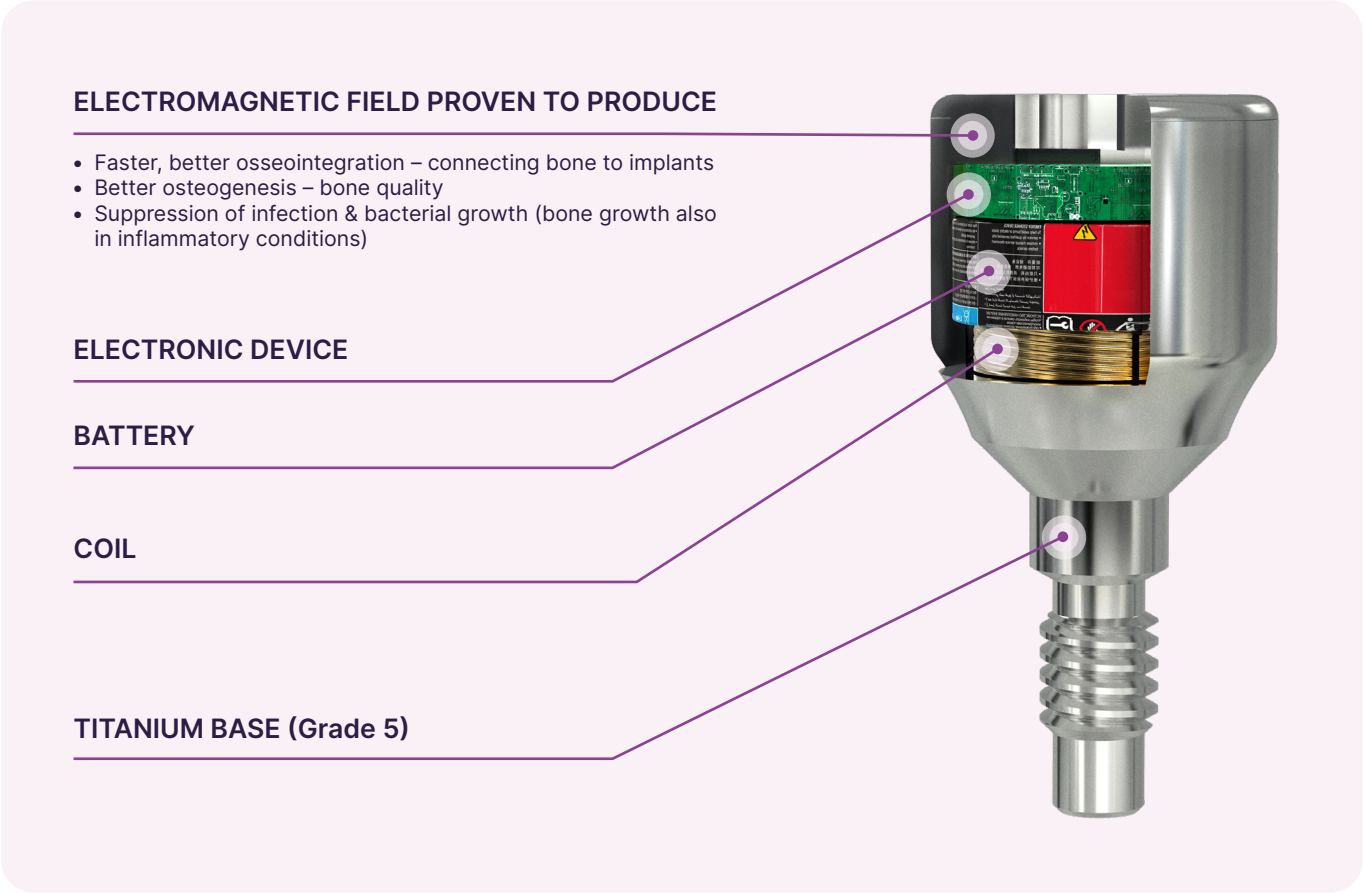

Figure 1. Internal structure and components of the MED healing abutment. Cross-sectional view of the miniaturized electromagnetic device.

2. Early implant healing and clinical challenges

Osseointegration is a dynamic, multistage process that begins immediately upon implant placement. It involves clot formation, inflammatory signaling, angiogenesis, recruitment of mesenchymal stem cells, osteoblast differentiation, and progressive bone remodeling [7]. Within the first few weeks, implants transition from primary mechanical stability to secondary biological stability, frequently undergoing the characteristic stability dip. During this period, active bone resorption, heightened inflammatory signaling, and early osteogenic differentiation occur simultaneously. If inflammation is excessive, vascularization is inadequate, or osteoblast recruitment is delayed, bone-to-implant contact may be compromised, prolonging healing and increasing susceptibility to micromotion [3].

While long-term implant survival rates typically exceed 90–95%, most biological and mechanical complications arise during this early healing phase. Marginal bone remodeling is particularly influential, as early crestal bone loss strongly predicts long-term peri-implant bone stability and soft-tissue health. These challenges are further compounded in patients with compromised bone quality, metabolic or inflammatory conditions, smoking history, or advanced age [1].

Conventional strategies, although effective at reducing immediate risk, remain largely passive. Healing abutments guide soft tissue maturation, surface modifications enhance osteoconductivity, and pharmacologic interventions primarily address infection or inflammation rather than actively promoting osteogenesis [4].

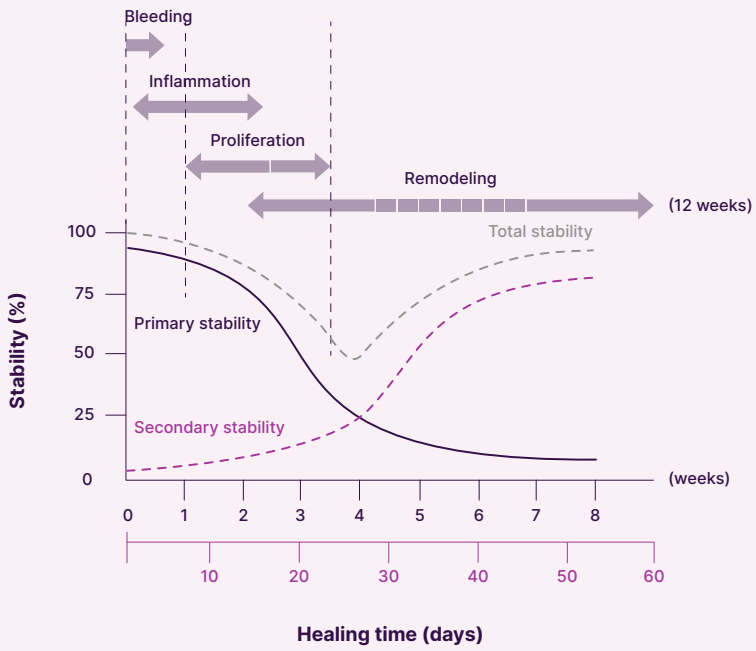

Figure 2. Biological and mechanical stability transition during early implant healing.
Graphical representation of implant stability over time, illustrating the transition from primary mechanical stability to secondary biological stability, the characteristic stability dip, and the overlapping phases of inflammation, proliferation, and remodeling during the first weeks post-placement.

3. Bioelectrical bone remodeling

Bone formation and remodeling are inherently regulated by bioelectrical signals. Endogenous electrical potentials, generated through mechanical loading, cellular metabolism, and ionic flux, direct osteoblast differentiation, osteoclast activity, angiogenesis, and mesenchymal stem cell recruitment [8]. These signals provide the physiological foundation for interventions using electromagnetic stimulation.

MEDs are designed to leverage this principle by delivering localized electromagnetic stimulation directly at the peri-implant bone interface. Unlike external PEMF devices that produce diffuse fields and rely on patient compliance, MED concentrates stimulation precisely where early bone formation is most critical; the coronal implant region. This targeted approach enhances trabecular organization, improves early mechanical anchorage, and integrates seamlessly into routine clinical workflows without increasing procedural complexity [2].

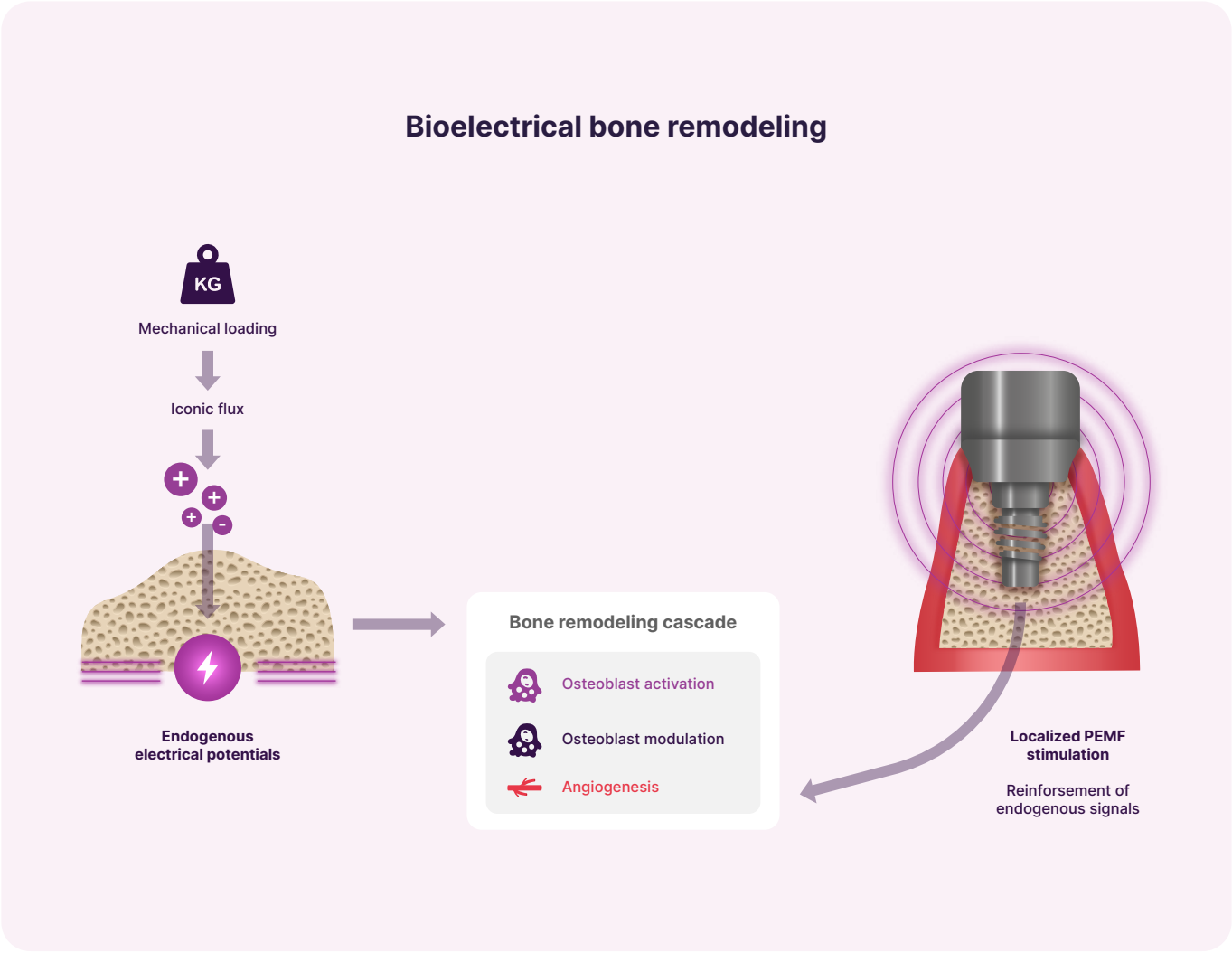

Figure 3. Bioelectrical regulation of bone remodeling and localized PEMF reinforcement.
Schematic representation of endogenous electrical potentials involved in bone remodeling and the mechanism by which localized PEMF stimulation reinforces osteoblast activation, angiogenesis, and trabecular bone formation at the peri-implant interface.

4. Pulsed electromagnetic field (PEMF) technology: clinical history and mechanisms

PEMF therapy has a decades long history in orthopedics, with FDA approval for nonunion fractures granted in 1979. Its safety and efficacy in stimulating bone repair without thermal or ionizing effects are well established [7]. At the cellular level, PEMF interacts with membrane receptors, ion channels, and intracellular signaling pathways to promote osteogenesis and modulate inflammation. Key osteogenic transcription factors, including Runx2, BMP2, and Wnt/β-catenin, are upregulated, promoting osteoblast differentiation and matrix deposition [5]. PEMF also modulates osteoclast activity, enhances angiogenesis through VEGF signaling, and supports mitochondrial function, ensuring adequate metabolic support during early bone formation. Inflammatory regulation is another critical mechanism. PEMF reduces pro-inflammatory cytokines such as TNF-α and IL-1β while increasing anti-inflammatory mediators including IL-10, supporting a balanced inflammatory environment essential for successful osseointegration [7]. Translational studies in dental and implant applications demonstrate enhanced peri-implant bone formation, improved trabecular connectivity, and early gains in implant stability [6–2].

Outcome parameter	PEMF group (test)	Control group (sham)	Conclusion
Marginal bone loss (MBL)	**Significantly lower MBL** at 6 and 12 weeks post-implantation.	Higher MBL compared to the PEMF group.	PEMF promotes **superior early bone preservation.**
Pro-inflammatory marker (TNF-α)	Showed only a **slight increase (15%)** in concentration during the first 4 weeks.	Demonstrated a **rapid increase of 30%** in concentration during the first 4 weeks.	PEMF successfully **modulates the inflammatory environment.**
Pro-inflammatory marker (IL-1β)	Exhibited a **slight decrease (20%)** between weeks 2 and 4, with **no peak concentration at 12 weeks.**	Showed a peak concentration at 12 weeks.	PEMF supports a **less inflammatory healing profile.**

Figure 4. Clinical inflammatory and marginal bone remodeling outcomes following PEMF stimulation. Comparative summary of clinical outcome parameters including marginal bone loss (MBL), TNF-α, and IL-1β levels in PEMF-treated versus control implants, demonstrating modulation of early inflammatory response and improved early bone preservation. (Data adapted from Nayak BP et al., J Clin Diagn Res 2020[3])

5. Magdent MED: integration of technology into clinical practice

The Magdent MED integrates PEMF technology within a miniaturized device embedded in a standard healing abutment. Once placed, it delivers continuous, localized electromagnetic stimulation to the surrounding peri-implant bone. By reinforcing endogenous bioelectrical signaling, MED accelerates de novo bone formation, stabilizes early mechanical anchorage, and regulates inflammation during the critical early healing period. Importantly, MED does not disrupt established clinical workflows. Placement mirrors that of a conventional healing abutment, activation is automated, and no additional instrumentation or procedural steps are required. Soft tissue management and restorative timelines remain unchanged, enabling seamless adoption by both general practitioners and specialists [2].

Prior to placement, the MED requires a brief external activation using the designated Magdent activator. This simple pre-placement step takes only a few seconds and does not alter the surgical or restorative protocol. Following activation, the MED is placed like a conventional healing abutment, without modification of the clinician's standard workflow.

5.1 Mechanism of action

Localized pulsed electromagnetic field stimulation delivered through the MED initiates a coordinated biological response at the implant interface during the early healing phase. Upon activation, PEMF interacts with peri-implant tissues and modulates key cellular pathways involved in osseointegration. Mechanistic evidence indicates that PEMF supports a balanced inflammatory profile by downregulating pro-inflammatory cytokines such as TNF-α and IL-1β while promoting anti-inflammatory mediators. In parallel, it enhances angiogenic signaling, including upregulation of vascular endothelial growth factors, improving local microcirculation, oxygenation, and nutrient delivery.

At the cellular level, PEMF promotes osteoblast differentiation and activity while influencing macrophage polarization toward a regenerative phenotype. These interconnected effects reinforce endogenous bioelectrical signaling and accelerate early bone matrix deposition at the implant surface. Clinically, this biological cascade supports improved early implant stability and a more predictable transition from primary mechanical stability to secondary biological stability [11].

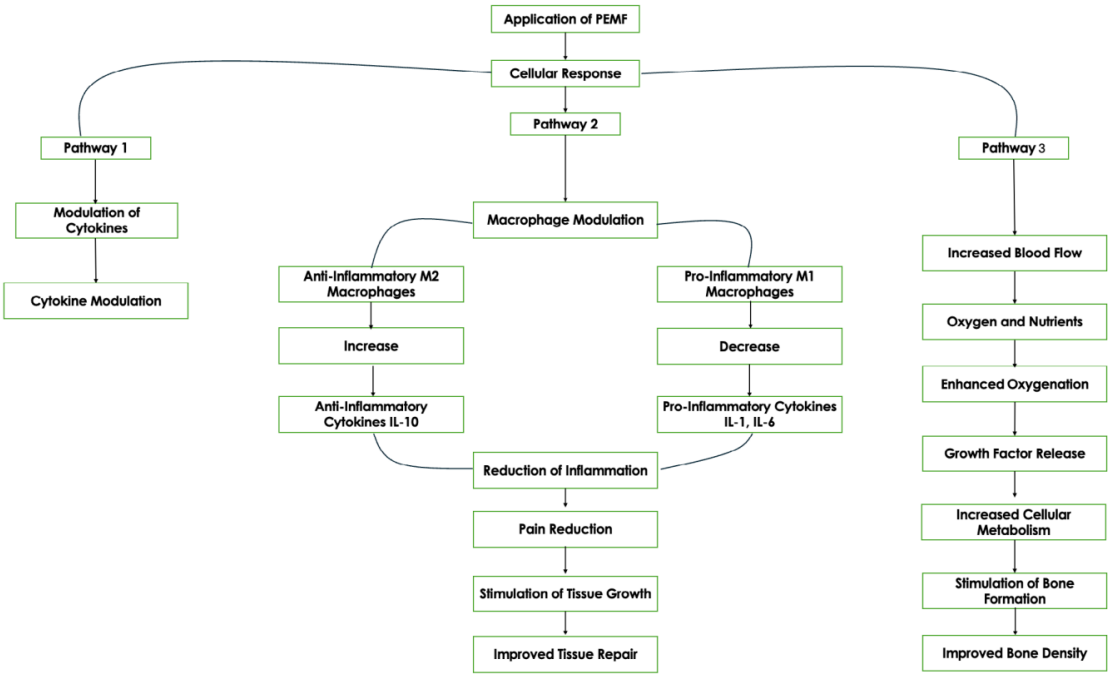

Figure 5. Pulsed electromagnetic field (PEMF) stimulation begins with the localized application of an electromagnetic signal to the peri-implant area. This external stimulus interacts with cellular membranes and ion channels, triggering an immediate biological response within the targeted tissues. The induced cellular response activates three primary pathways. First, PEMF modulates cytokine signaling, shifting the balance between pro- and anti-inflammatory mediators. Second, it enhances local microcirculation and angiogenic signaling, improving oxygen and nutrient delivery to the healing environment. Third, it influences immune cell activity, supporting a regenerative cellular profile during the early healing phase. Together, these coordinated biological processes create a favorable environment for tissue repair and bone remodeling at the implant interface. (Data adapted from Nayak BP et al., J Clin Diagn Res 2020)[4].

6. Clinical evidence

6.1 Randomized controlled trial

In a randomized controlled clinical trial involving 19 partially edentulous patients and 40 implants, the effect of continuous pulsed electromagnetic field (PEMF) stimulation delivered via a miniaturized electromagnetic device (MED) healing abutment was evaluated during the early healing phase following implant placement. Implants were randomly assigned to receive either an active MED or a sham healing abutment, with implant stability measured by resonance frequency analysis at baseline and at 2, 4, 6, 8, and 12 weeks post-placement. While intergroup comparisons over time did not reach statistical significance, intragroup analysis revealed a markedly different stability trajectory between groups. During the critical first two weeks, corresponding to the transition from primary to secondary stability, implants in the MED group demonstrated a mean increase in implant stability quotient (ISQ) of 6.8 percent relative to baseline, whereas control implants exhibited a mean decrease of 7.6 percent. This resulted in a net early stability difference of approximately 13 percent in favor of the MED-treated implants. Over the full 12-week observation period, implants exposed to PEMF showed a statistically significant overall increase

in stability of 13 percent, while control implants demonstrated an overall decrease of 2 percent, highlighting a sustained benefit on early and mid-term implant stability [3].

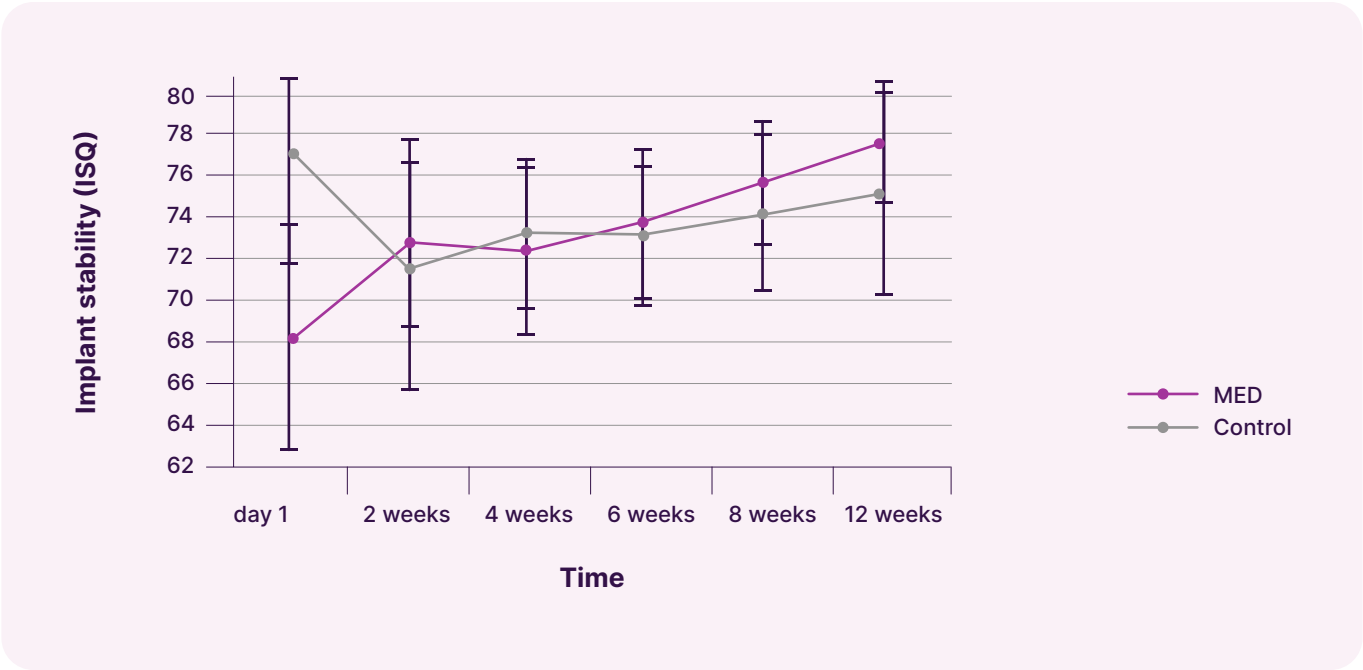

Figure 6. Changes in implant stability in the MED and control groups over time [3].

Beyond mechanical stability, the trial also assessed peri-implant bone remodeling and inflammatory activity, providing additional insight into the biological processes underlying the observed stability differences. Radiographic analysis performed at 6 and 12 weeks demonstrated significantly lower marginal bone loss around MED-treated implants compared with controls at both timepoints.

Figure 7. Box-plot with min-max values for the control (C) and test (MED) groups at 6 and 12 weeks using the Mann-Whitney test, *p <0.05 [3].

In parallel, analysis of peri-implant crevicular fluid revealed modulation of the early inflammatory response in the PEMF group. During the first four weeks of healing, TNF-α concentrations increased by approximately 30 percent in control implants, compared with a more limited increase of around 15 percent in MED-treated implants. Levels of IL-1β also showed a more regulated temporal pattern in the PEMF group, without the late peak observed in controls. Taken together, these findings suggest that PEMF stimulation delivered via the MED not only alters the early mechanical stability trajectory by mitigating the typical post-placement stability dip, but is also associated with reduced early inflammatory signaling and more favorable peri-implant bone remodeling during the initial phases of osseointegration [3].

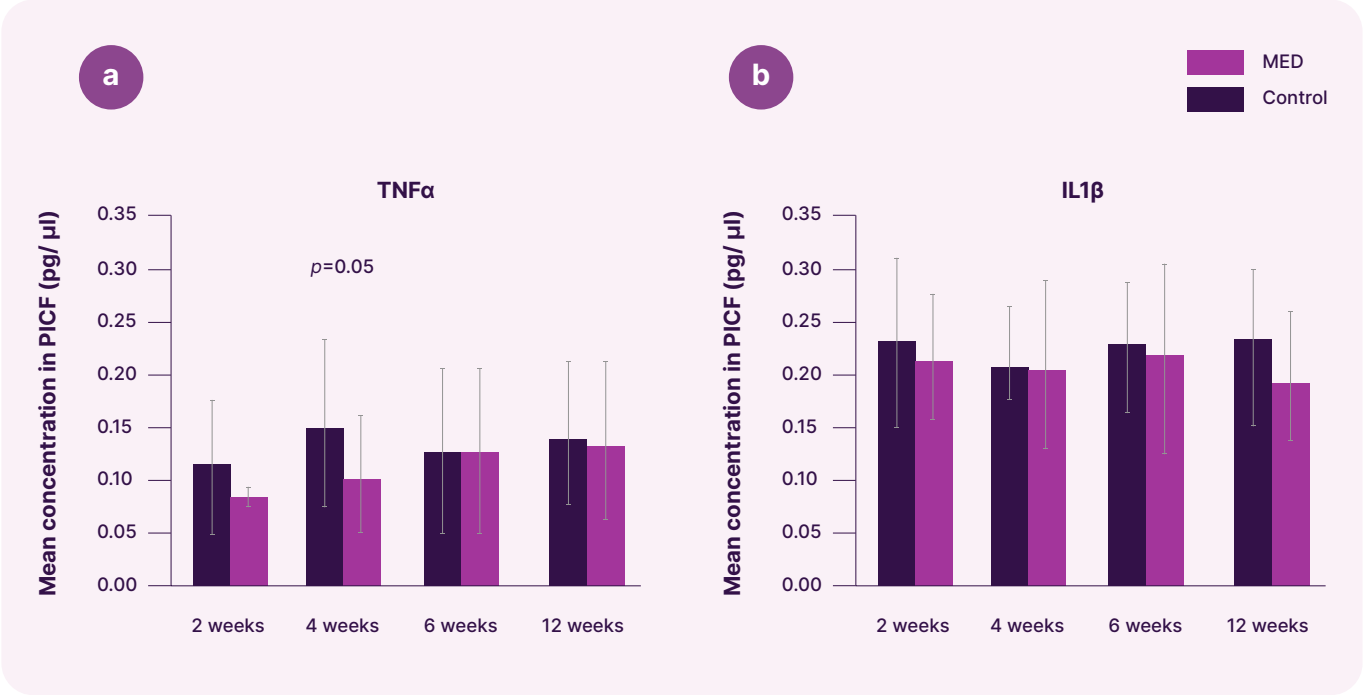

Figure 8. Changes in cytokine levels in the MED and control groups over time, an analysis of variance (ANOVA), and Tukey post hoc test that followed ANOVA, were used. If homogenity of variance was significant, the Kruskal-Wallis test was used; results are presented as mean ± SD of the mean. *$p < 0.05$ control vs MED [3].

6.2 Independent human ISQ study

A prospective, case-controlled human clinical study evaluated the effect of a miniaturized electromagnetic device (MED) healing abutment on early dental implant stability in 12 partially edentulous patients, comprising a total of 28 implants placed in the maxilla and mandible. Implants were fitted either with an active MED healing cap or a standard non-active healing cap, while surgical and postoperative protocols were identical between groups. Implant stability was assessed using resonance frequency analysis at implant placement and at predefined early healing timepoints. The study focused exclusively on mechanical stability outcomes, with implant stability quotient (ISQ) as the primary endpoint, and did not assess inflammatory or radiographic parameters, positioning it as a targeted evaluation of early mechanical anchorage [2].

Results demonstrated consistently higher implant stability in MED-treated implants compared with controls throughout the early healing phase. At 15 days post-placement, maxillary implants fitted with MED healing caps already showed significantly higher ISQ values compared with controls (66.2 versus 62.1). At 30 days, stability gains were evident in both anatomical locations, with MED-treated implants reaching ISQ values of 73.5 versus 66.7 in the mandible and 74.0 versus 65.0 in the maxilla. These differences persisted at 50 days post-placement, with MED-treated maxillary implants maintaining higher ISQ values (75.4 versus 68.5). No device-related complications were reported, and healing was uneventful in all patients. Collectively, this study provides independent human clinical confirmation that continuous, localized PEMF stimulation delivered via a MED healing abutment is associated with improved mechanical implant stability during the early post-placement period [2].

Resonance frequency analysis results

	Mandible			Maxilla		
	Control	MED	pV	Control	MED	pV
Baseline	56.2 ± 4.8	59.33 ± 4	0.24	60.9 ± 1.6	61.2 ± 1.2	0.7
Day 15	61.3 ± 4.8	66.3 ± 4	0.07	62.1 ± 2.1	66.2 ± 0.7	0.0008*
Day 30	66.7 ± 4.8	73.5 ± 3.2	0.016	65 ± 2.3	74 ± 1.7	<0.05*
Day 50				68.5 ± 8.5	68.5 ± 8.5	<0.05*

Results are reported as mean ± SD. MED, miniaturized electromagnetic device. *P <0.5 MED vs Control group, T test.

Figure 9. Resonance frequency analysis (ISQ) values for implants fitted with a miniaturized electromagnetic device (MED) healing abutment versus control healing abutments in the mandible and maxilla at baseline, 15, 30 and 50 days. MED-treated implants show consistently higher stability values from day 15 onwards, with statistically significant differences at days 30 and 50 ($P < 0.05$) [3].

7. Preclinical evidence: micro-CT and histology

Preclinical evaluation of the PEMF-emitting healing cap was conducted in a controlled rabbit model to quantify its effects on early peri-implant bone formation and osseointegration at the microstructural level. In this study, 22 dental implants were placed in the proximal tibial metaphysis of New Zealand White rabbits and fitted either with an active PEMF-emitting healing cap or with an identical non-active control cap. Animals were euthanized at 2 and 4 weeks post-implantation, and peri-implant bone was analyzed using high-resolution micro-computed tomography and histological assessment.

Micro-CT analysis demonstrated that the osteogenic effects of PEMF stimulation were spatially localized, with the most pronounced changes observed in the coronal peri-implant region, corresponding to the area of highest electromagnetic field intensity. As early as 2 weeks post-placement, PEMF-treated implants showed a 56 percent increase in trabecular bone volume fraction (BV/TV) compared with controls, accompanied by a 37 percent increase in trabecular number and a 73 percent increase in trabecular connectivity density. At 4 weeks, these effects persisted and further increased, with BV/TV remaining 69 percent higher and trabecular number 34 percent higher in the PEMF group, while trabecular thickness remained unchanged, indicating stimulation of new trabecular formation rather than thickening of existing bone [1].

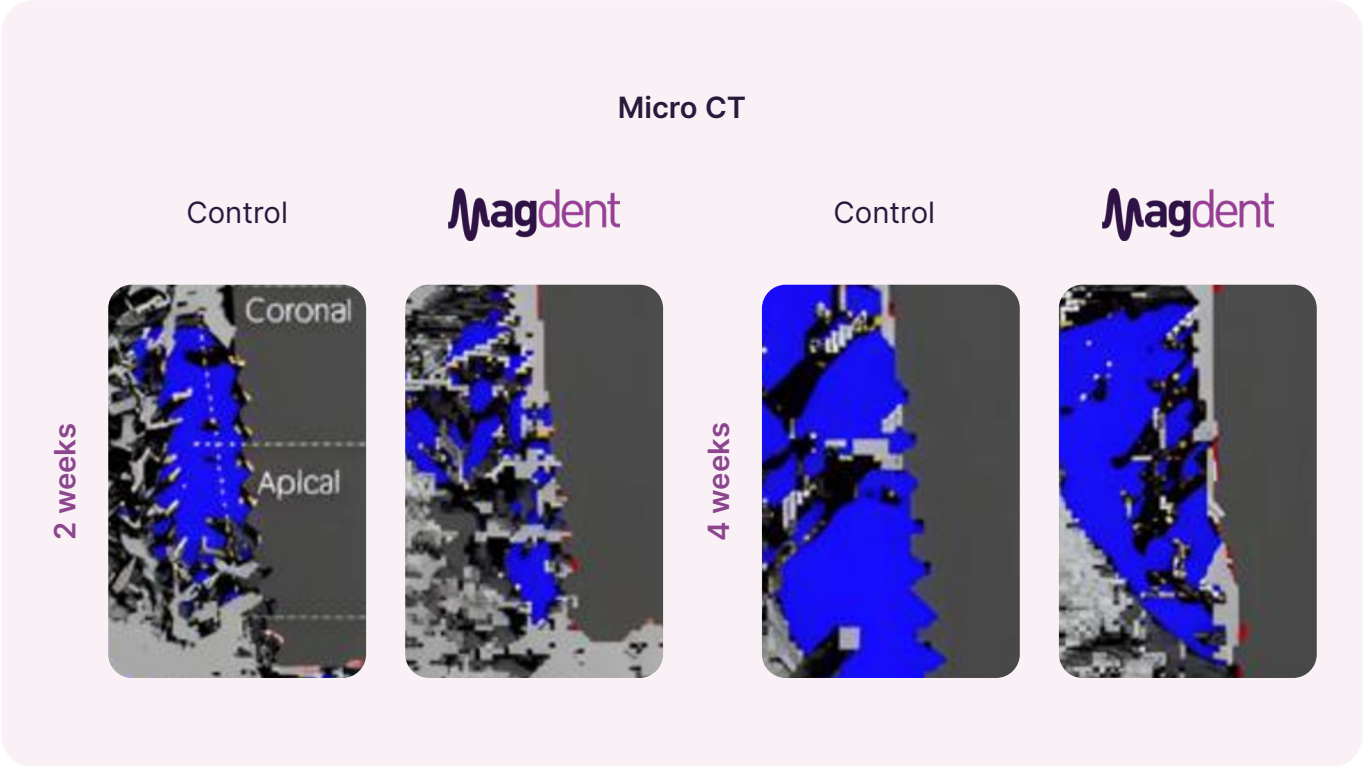

Figure 10. Representative micro-CT sections at 2 and 4 weeks around control and PEMF-treated implants in the rabbit tibia model, adapted from Barak et al. [1].

Histological analysis corroborated the micro-CT findings and provided direct evidence of accelerated osseointegration at the bone-implant interface. Two weeks after implantation, PEMF-treated implants demonstrated a 48 percent higher bone-to-implant contact (BIC) compared with controls, with newly formed trabecular and woven bone observed in direct contact with the implant surface and no intervening fibrous tissue. This increase in BIC remained stable through the 4-week timepoint, at which lamellar and woven bone were consistently observed along the implant perimeter in the PEMF group. Notably, the osteogenic effects were largely confined to the coronal half of the implant, while the apical region showed no significant differences between groups, reflecting the localized nature of the electromagnetic stimulation. Taken together, these findings indicate that continuous, localized PEMF delivery via the healing cap accelerates early peri-implant bone formation and osseointegration, achieving structural and interfacial bone characteristics at 2 weeks that are typically reported at substantially later healing stages in conventional implant integration models [1].

Figure 11. Histological evaluation of bone-to-implant contact (BIC) at 2 and 4 weeks.
Ground section histology images comparing control and PEMF-treated implants. PEMF stimulation shows increased bone-to-implant contact and earlier formation of woven and lamellar bone, primarily localized in the coronal implant region. (Dr. Adriano Piattelli, Prof. Shlomo Barak)

8. Mechanistic understanding: in-vitro biological pathways

Mechanistic insights into the biological effects of pulsed electromagnetic field stimulation are derived from in-vitro and preclinical studies reported in the literature and provide contextual support for the clinical and preclinical outcomes observed with MED therapy. Experimental models have shown that exposure to PEMF can influence key cellular processes involved in bone healing, including osteoblast differentiation, osteoclast activity, and angiogenic signaling. In inflammatory environments, PEMF exposure has been associated with modulation of pro-inflammatory cytokine expression and shifts in macrophage polarization toward a pro-regenerative phenotype. Additional in-vitro studies suggest that PEMF stimulation can enhance cellular energy metabolism and support vascularization through upregulation of angiogenic pathways. While these mechanistic findings do not constitute clinical outcome evidence, they offer biological plausibility for the observed effects of localized PEMF delivery on early implant stability and peri-implant bone formation [5–2].

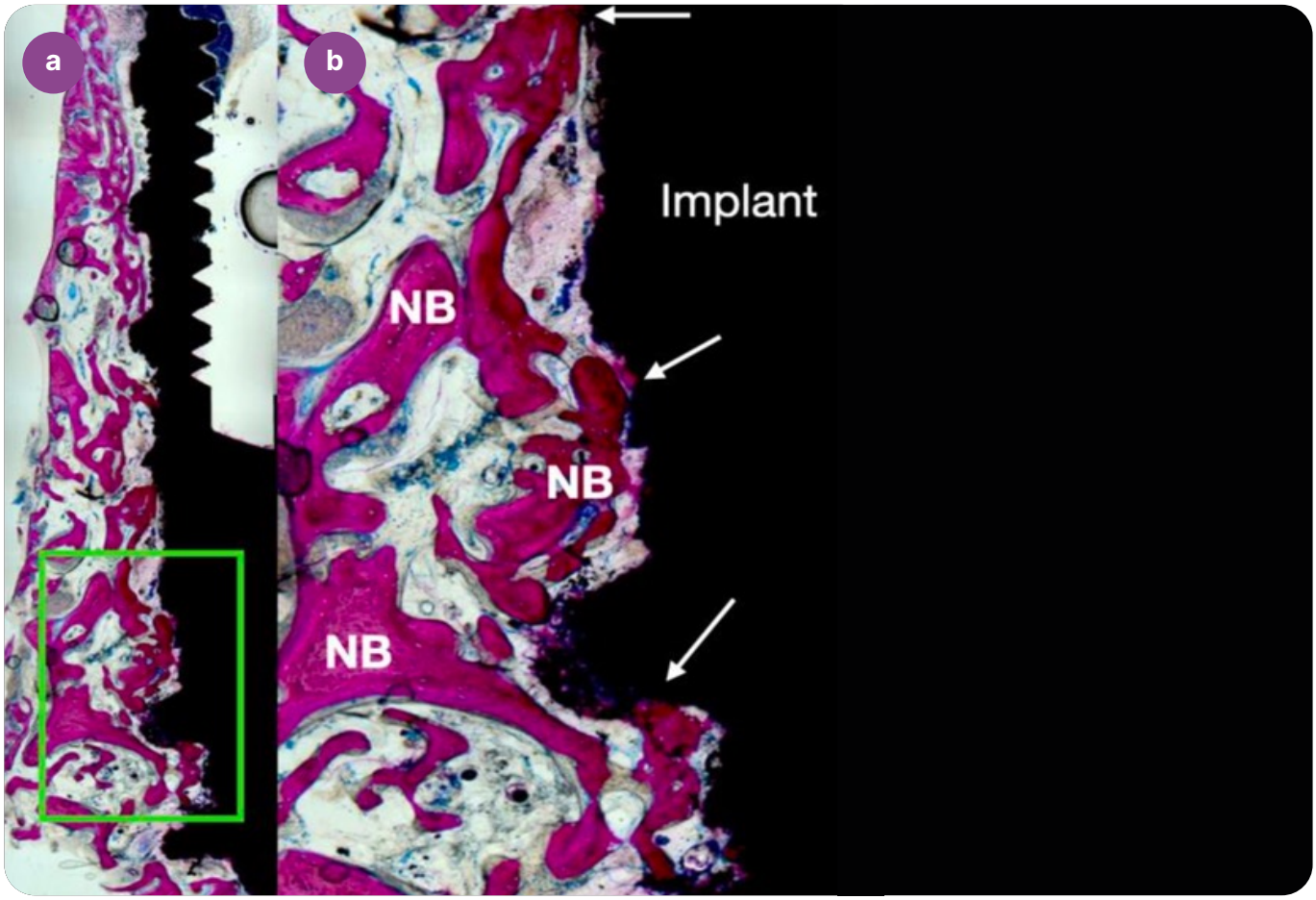

Figure 12. Histological ground section of an experimental dental implant retrieved after 60 days in the human maxilla with MED-assisted PEMF stimulation: (a) overview of the implant showing continuous bone-to-implant contact along the fixture; (b) magnified view demonstrating direct ossification and increased bone stock in type IV bone (adapted from Mayer et al.[9])

9. Clinical implications and practical application

Mechanistic insights into the biological effects of pulsed electromagnetic field stimulation are derived from in-vitro and preclinical studies reported in the literature and provide contextual support for the clinical and preclinical outcomes observed with MED therapy. Experimental models have shown that exposure to PEMF can influence key cellular processes involved in bone healing, including osteoblast differentiation, osteoclast activity, and angiogenic signaling. In inflammatory environments, PEMF exposure has been associated with modulation of pro-inflammatory cytokine expression and shifts in macrophage polarization toward a pro-regenerative phenotype. Additional in-vitro studies suggest that PEMF stimulation can enhance cellular energy metabolism and support vascularization through upregulation of angiogenic pathways. While these mechanistic findings do not constitute clinical outcome evidence, they offer biological plausibility for the observed effects of localized PEMF delivery on early implant stability and peri-implant bone formation [5–2].

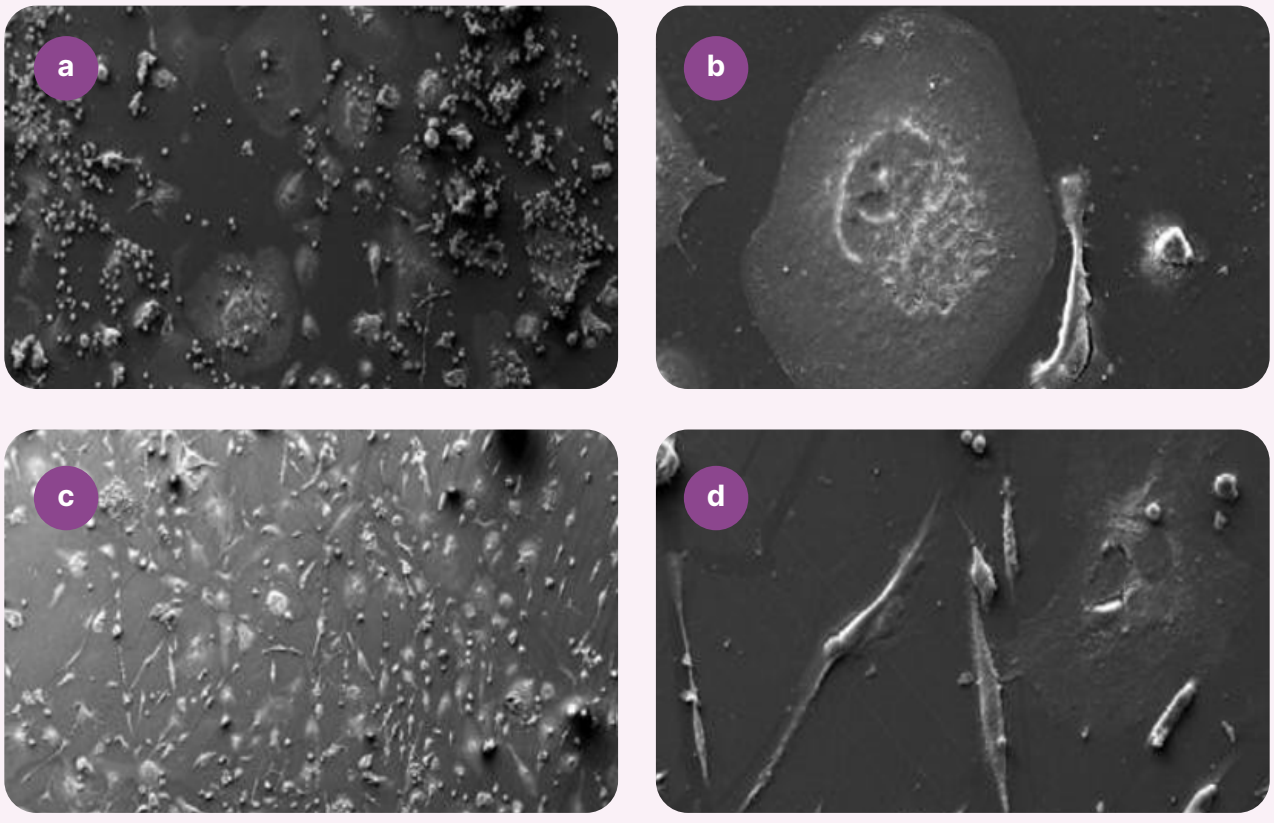

Figure 13. In vitro studies demonstrate that PEMF exposure is associated with morphological and phenotypic changes in macrophage models consistent with a pro-regenerative profile. SEM analyses of THP-I: (**a** and **b**) in normal conditions, cells acquire a round morphology typical of MI phenotype; meanwhile, (**c** and **d**) in presence of PEMF, they acquire a fusiform morphology typical of M2 phenotype. (**a** and **c**) Scale bar: 200 µm, (**b** and **d**) Scale bar: 30 µm [10].

10. Summary and conclusions

The collective findings from the randomized controlled clinical trial, the independent human implant stability study, and the preclinical micro-CT and histological investigation demonstrate that localized pulsed electromagnetic field stimulation delivered via a miniaturized electromagnetic device represents a meaningful advancement in early implant healing. Across human and animal models, MED therapy consistently influenced the most vulnerable phase of implant integration: the transition from primary mechanical stability to secondary biological stability. Clinical data show that MED-treated implants follow a distinctly different early stability trajectory, characterized by mitigation of the typical post-placement stability dip and sustained gains in implant stability quotient values during the first weeks of healing. In the randomized controlled trial, MED-treated implants exhibited a net early stability advantage of approximately 13 percent compared with controls, while the independent human study confirmed significantly higher ISQ values at 15, 30, and 50 days post-placement [1–2–3].

Beyond mechanical stability, the combined evidence indicates that MED therapy favorably influences the biological processes underlying osseointegration. In the randomized clinical study, reduced early TNF-α expression and lower marginal bone remodeling were observed at MED-treated sites, suggesting a more regulated inflammatory environment during early healing. These clinical observations are supported by preclinical findings demonstrating accelerated peri-implant bone formation at the microstructural level. In the rabbit model, localized PEMF stimulation resulted in substantial increases in trabecular bone volume fraction, trabecular number, and connectivity density as early as two weeks post-implantation, alongside a 48 percent increase in bone-to-implant contact. Importantly, these effects were spatially concentrated in the coronal peri-implant region, which plays a critical role in early mechanical anchorage and long-term crestal bone support [1–3].

Taken together, these studies provide converging evidence that continuous, localized PEMF delivery via a healing abutment can actively support early osseointegration by stabilizing mechanical anchorage, enhancing peri-implant bone quality, and modulating early inflammatory responses, without altering established surgical or restorative workflows. MED therapy integrates seamlessly into routine clinical practice, functioning as a workflow-compatible adjunct rather than a disruptive intervention. By transforming early implant healing from a passive, risk-prone interval into an actively supported biological process, MED has the potential to improve predictability during the most sensitive stage of implant integration and to support more confident clinical decision-making across a wide range of treatment scenarios [1–2–3–5].

For clinicians interested in reviewing additional clinical evidence, understanding system compatibility, or learning more about the application of MED therapy in daily practice, further information is available at **www.magdentmed.com.** *Our website provides access to supporting clinical materials and options to explore MED integration in more detail.*

11. Clinical impact of Magdent MED

Accelerated early osseointegration

Up to 3× enhanced early stability development during the first 30 days, as demonstrated in peer-reviewed clinical studies, supporting a faster and more predictable transition from primary to secondary stability.

Microbiome modulation

Influences pathogenic biofilm activity and supports a balanced peri-implant microbial environment, contributing to long-term implant stability.

Denser Peri-implant bone

Preclinical micro-CT and histologic analyses demonstrate increased bone-to-implant contact and improved trabecular bone density at the implant interface.

Non-surgical

Delivers localized PEMF through a standard healing abutment design without protocol changes or additional intervention.

Mitigation of stability dip

Supports biological stability during the early remodeling phase, helping reduce the characteristic temporary decrease in implant stability.

Balanced inflammatory profile

Modulates pro- and anti-inflammatory signaling pathways, supporting a controlled healing environment during early osseointegration.

Scientific note: Benefits derived from peer-reviewed preclinical and clinical studies referenced in this white paper.

12. References

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