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Effect of Low-Intensity Pulsed Ultrasound on Osseointegration of Endosseous Dental Implants: A Split-Mouth Clinical Study

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KEYWORDS

Dental implant

Osseointegration

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ABSTRACT:

Introduction Dental implants are a predictable modality for oral rehabilitation, with successful outcomes largely dependent on rapid and stable osseointegration. However, achieving optimal early bone–implant integration remains a clinical challenge, particularly in compromised bone conditions. Low-Intensity Pulsed Ultrasound (LIPUS), a non-invasive modality known to stimulate osteogenesis and angiogenesis, has shown promising results in fracture healing, but its clinical role in enhancing dental implant osseointegration is not yet well established.

Objectives To evaluate the effect of Low-Intensity Pulsed Ultrasound (LIPUS) therapy on implant stability and peri-implant bone density in endosseous dental implants using a split-mouth clinical design.

Methods A prospective split-mouth clinical study was conducted on 25 partially edentulous patients requiring bilateral mandibular implants, yielding 50 implant sites. Each patient received one test implant exposed to postoperative LIPUS and a contralateral control implant without adjunctive ultrasound, minimizing inter-individual variability. Implant stability was measured at 1, 2, and 3 months using Resonance Frequency Analysis and expressed as Implant Stability Quotient (ISQ) values, while peri-implant bone density was assessed at the same intervals using Cone Beam CBCT. Paired t-tests were used to compare test and control implants at each time point.

Results: Mean ISQ values increased over time in both groups, but were consistently higher for LIPUS-treated implants. At 1, 2, and 3 months, mean ISQ values were 64.9, 71.7, and 77.8 in the LIPUS group and 62.1, 68.2, and 73.3 in the control group, respectively, with statistically significant differences at all time points ($p = 0.004$, 0.001, and <0.001, respectively). CBCT analysis similarly showed progressive increases in peri-implant bone density from 1 to 3 months in both groups, with higher mean values and a steeper upward trend for LIPUS-treated sites, indicating enhanced bone formation and maturation.

Conclusions: LIPUS therapy significantly improves early osseointegration of dental implants by increasing implant stability and peri-implant bone density during the initial healing period. These findings support LIPUS as a safe, non-invasive adjunct to conventional implant therapy, particularly when accelerated or enhanced early osseointegration is desired.

1. Introduction

Dental implants are widely accepted and highly predictable for replacing missing teeth, offering high long-term success rates and functional rehabilitation for edentulous patients. The cornerstone of implant success lies in predictable osseointegration, defined as a direct structural and functional connection between living bone and the implant surface.[1] Despite continuous improvements in implant materials, surface topography, and surgical techniques, achieving rapid and stable osseointegration in all bone qualities remains a clinical challenge.[2] Early failure of implants during the healing phase often results from inadequate initial stability and impaired bone remodeling.[3]

To overcome these limitations, various biophysical and biochemical adjunctive modalities have been explored to enhance peri-implant bone healing.[4] Among these, Low-Intensity Pulsed Ultrasound (LIPUS) has attracted interest due to its non-invasive and osteogenic properties. LIPUS generates acoustic pressure waves that promote mechanotransduction, stimulating cellular activities such as osteoblastic proliferation, differentiation, extracellular matrix production, and angiogenesis.[5-7] Clinically, it has demonstrated significant efficacy in stimulating fresh and delayed fracture healing and enhancing bone regeneration in orthopedic applications.[8]

However, clinical evidence supporting the role of LIPUS in implant dentistry remains limited. Most existing studies have

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been conducted in animal models or in vitro, and few controlled clinical evaluations have assessed its impact on dental implant osseointegration.[9,10] Given its potential biological advantages and non-invasive nature, further research is warranted to establish clinical protocols for its use in implant therapy.

The present split-mouth clinical study aimed to evaluate the effect of LIPUS therapy on implant stability and peri-implant bone density in endosseous dental implants. By comparing test and control sides within the same individual, inter-individual variables were minimized, allowing a reliable assessment of LIPUS efficacy in enhancing early osseointegration.

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2. Objectives

The primary objective of the present study was to evaluate the effect of Low-Intensity Pulsed Ultrasound (LIPUS) therapy on the osseointegration of endosseous dental implants. This was assessed by comparing implant stability using Resonance Frequency Analysis (Implant Stability Quotient values) and peri-implant bone density using Cone Beam Computed Tomography between LIPUS-treated implants and untreated control implants in a split-mouth clinical design.

The secondary objective was to determine whether LIPUS therapy enhances early healing dynamics around dental implants during the initial postoperative period, thereby potentially improving clinical outcomes and reducing the risk of early implant failure.

3. Methods

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. A prospective split-mouth clinical study was conducted to evaluate the effect of Low-Intensity Pulsed Ultrasound (LIPUS) on osseointegration of endosseous dental implants. Each patient received one test implant and one control implant in contralateral mandibular sites, thereby serving as their own control and minimizing inter-individual variability.

The study included 25 partially edentulous patients (13 males and 12 females) requiring bilateral mandibular dental implants, yielding a total of 50 implant sites (25 test and 25 control). Eligible patients were between 20 and 50 years of age, had adequate bone volume to accommodate standard implants at the planned mandibular sites, and were in good systemic health. All participants were selected from patients who reported for implant-supported rehabilitation and met the predefined inclusion and exclusion criteria.

The inclusion criteria for the study comprised patients aged between 20 and 50 years who were partially edentulous and required bilateral mandibular implants in comparable sites. Only individuals with adequate bone height and width suitable for implant placement without the need for extensive grafting were selected. Additionally, participants were required to be in good systemic health and capable of attending scheduled follow-up visits.

The exclusion criteria included patients with systemic diseases or conditions known to affect bone metabolism, such as uncontrolled diabetes, metabolic bone disorders, or those undergoing long-term corticosteroid therapy. Individuals with a history of smoking or other forms of tobacco use, pregnant women, patients who had previously undergone radiotherapy in the head and neck region, and those presenting with active oral infections or poor oral hygiene were also excluded from the study.

In each patient, one implant site was assigned to the test group (implants receiving postoperative LIPUS therapy) and the contralateral site to the control group (implants receiving no LIPUS therapy). This split-mouth design allowed direct comparison between LIPUS-treated and untreated implants within the same individual, reducing variability related to patient-specific factors such as bone quality and healing capacity.

All implants were placed under local anesthesia following standard aseptic surgical protocols. Crestal incisions were made, full thickness mucoperiosteal flaps were elevated, and osteotomies were prepared according to the implant manufacturer’s drilling sequence under copious irrigation. Implants of appropriate diameter and length were inserted to achieve optimal primary stability, which was verified clinically at the time of placement. Flaps were repositioned and sutured, and all patients received standardized postoperative care, including routine analgesics, antibiotics when indicated, and uniform postoperative instructions regarding diet and oral hygiene.

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LIPUS therapy was initiated postoperatively on the designated test side after initial soft tissue healing, as per the study protocol. A commercially available therapeutic ultrasound device capable of delivering low-intensity pulsed output was used. The ultrasound probe was applied externally over the implant site with a suitable coupling medium, and LIPUS was administered according to standard therapeutic parameters for bone stimulation (low-intensity pulsed mode, fixed frequency and duration per session). Treatment was delivered at regular intervals for the prescribed period during the early healing phase. (Figure 1) Control sites did not receive any adjunctive ultrasound therapy but were otherwise managed identically to test sites, including medications and instructions.

Figure 1: Clinical application of Low-Intensity Pulsed Ultrasound over the lateral mandibular region in multiple patients following implant placement.

Implant stability: Implant stability was evaluated using Resonance Frequency Analysis (RFA), and the measurements were expressed as Implant Stability Quotient (ISQ) values. ISQ recordings were obtained for each implant at 1, 2, and 3 months postoperatively. At each time point, the RFA transducer was attached according to the manufacturer's instructions, and the obtained readings were documented for both test and control implants.

Peri-implant bone density was assessed using Cone Beam Computed Tomography (CBCT) scans at 1, 2, and 3 months postoperatively. Standardized CBCT imaging parameters were used for all patients to ensure consistency. The peri-implant region around each fixture was examined, and density-related values were recorded at each interval for both LIPUS-treated and control implants, providing a radiographic estimate of bone formation and maturation over time.

4. Results

All 25 patients completed the 3-month follow-up, providing 50 implants (25 LIPUS-treated and 25 control) for analysis. Mean Implant Stability Quotient (ISQ) values increased progressively over time in both groups, indicating ongoing osseointegration during the early healing period. At each evaluated interval, LIPUS-treated implants demonstrated higher mean ISQ values than their contralateral controls, and these differences were statistically significant.

At 1 month, the mean ISQ was 64.9 for the LIPUS group and 62.1 for the control group ($p = 0.004$). At 2 months, mean ISQ values rose to 71.7 in the LIPUS group and 68.2 in the control group ($p = 0.001$). By 3 months, the mean ISQ reached 77.8 for LIPUS-treated implants versus 73.3 for control implants ($p < 0.001$). These findings indicate that adjunctive LIPUS therapy provided a consistent and statistically significant improvement in early implant stability at all follow-up intervals. Table 1 summarizes the ISQ data for both groups over time.

Peri-implant bone density assessed by Cone Beam Computed Tomography (CBCT) also increased from 1 to 3 months in both groups, reflecting progressive bone formation and maturation around the implants. At each time interval, the LIPUS-treated side exhibited higher mean CBCT-derived bone density than the control side, with a more pronounced upward trend over time.

These radiographic findings are illustrated in Figure 2, which shows the mean peri-implant bone density for LIPUS and control implants at 1, 2, and 3 months. Taken together, the ISQ and CBCT outcomes suggest that LIPUS therapy enhances early osseointegration by improving both mechanical implant stability and bone density in the surrounding bone during the initial healing period.

Time interval	LIPUS mean ISQ	Control mean ISQ	p-value
1 month	64.9	62.1	0.004
2 months	71.7	68.2	0.001
3 months	77.8	73.3	<0.001

***Table 1**. Mean Implant Stability Quotient (ISQ) values for implants in the Low-Intensity Pulsed Ultrasound (LIPUS) and control groups at 1, 2, and 3 months postoperatively. LIPUS-treated implants showed significantly higher ISQ values than controls at all time points (paired t-test, $p < 0.05$).*

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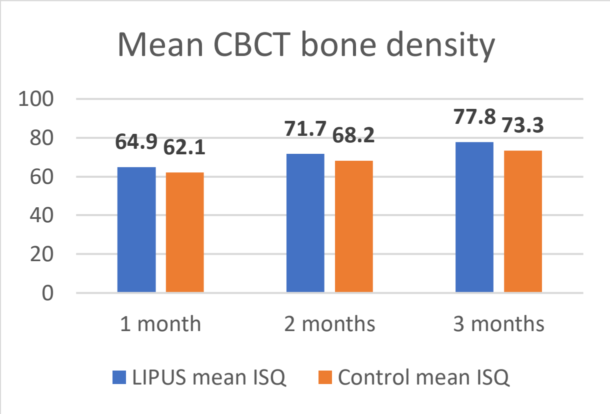

Figure 2. Mean CBCT-derived peri-implant bone density (HU) for LIPUS-treated and control implants at 1, 2, and 3 months. Bar chart demonstrating consistently higher mean bone density values and a steeper increase over time on the Low-Intensity Pulsed Ultrasound (LIPUS) side compared with the control side, indicating enhanced peri-implant bone formation and maturation.

5. Discussion

The present split-mouth clinical study demonstrated that adjunctive Low-Intensity Pulsed Ultrasound (LIPUS) therapy significantly enhanced early implant stability and peri-implant bone density compared with contralateral control sites without ultrasound. The progressive increase in Implant Stability Quotient (ISQ) values in both groups reflects the normal course of osseointegration, whereas the consistently higher ISQ values at 1, 2, and 3 months on the LIPUS side indicate that ultrasound accelerates this process and improves early mechanical anchorage of implants.[9,10] This is clinically relevant because insufficient early stability has been associated with a higher risk of early implant failure, particularly in poorer-quality bone.[2,3]

The biological basis for the observed clinical effect can be attributed to the ability of LIPUS to deliver low-magnitude mechanical micro-stimulation to bone tissue, thereby activating mechano-transduction pathways in osteogenic cells.[5,6] In vitro and animal studies have shown that LIPUS enhances osteoblast proliferation and differentiation, increases extracellular matrix production, and promotes mineralized nodule formation, accompanied by upregulation of osteogenic markers such as alkaline phosphatase and osteocalcin.[7,9] Recent work has further demonstrated that LIPUS can modulate bone marrow mesenchymal stem cells and focal adhesion signalling via integrin-mediated pathways, supporting new bone formation at the bone–implant interface.[9] These mechanisms are consistent with the higher peri-implant bone density measured radiographically in the LIPUS group in the present study.

Angiogenesis is another critical component of successful osseointegration, and LIPUS has been reported to enhance endothelial cell migration, tube formation, and secretion of pro-angiogenic mediators such as nitric oxide and prostaglandin E2.[7,9] By simultaneously promoting osteogenesis and angiogenesis, LIPUS may create a more favourable microenvironment for bone remodelling and maturation around dental implants, which is reflected in the faster and greater gains in bone density and ISQ values observed at the LIPUS-treated sites.[5,8,9] Thus, the mechanical improvements in stability documented in this study likely mirror genuine qualitative changes in the surrounding peri-implant bone.

The present findings are consistent with previous reports from both the orthopaedic and dental literature that highlight the beneficial impact of LIPUS on bone healing.[5,8,9] In fracture management, low-intensity pulsed ultrasound has been shown to accelerate union and improve radiographic healing, supporting its role as an effective non-invasive adjunct to conventional treatment.[8,12] More recently, a systematic review and meta-analysis reported that LIPUS exerts a positive osteogenic effect on peri-implant bone, improving bone–implant contact and bone density around dental implants.[9,13] Experimental and translational studies also suggest that LIPUS may enhance peri-implant bone regeneration and osseointegration in animal models, further supporting the results of this clinical trial.[9]

Methodologically, the split-mouth design used in this study strengthens internal validity by allowing each patient to act as their own control, thereby reducing the influence of inter-individual variability in bone quality, systemic health, and healing potential.[1,2] All implants were placed using a standardized surgical protocol, the same implant system, and uniform postoperative care, which minimizes confounding from procedural differences. Resonance Frequency Analysis and Cone Beam Computed Tomography provided complementary objective measures: ISQ values reflect mechanical stability at the bone–implant interface, whereas CBCT-based bone density offers a radiographic estimate of the evolving quality of peri-implant bone.[10] The concordance between these two outcome measures in favor of LIPUS strengthens the interpretation that ultrasound stimulation enhances early osseointegration.

Despite these strengths, several limitations must be acknowledged. The follow-up period was limited to three months and focused on the early healing phase; therefore, the long-term impact of LIPUS on marginal bone levels, prosthetic outcomes, and implant survival could not be assessed.[9] Histologic evaluation of bone–implant contact was not feasible in this clinical setting, so microstructural changes at the interface were inferred indirectly from ISQ and CBCT measurements rather than observed directly. Additionally,

although the sample size was adequate to detect statistically significant differences in the primary outcomes, it was relatively modest and drawn from a single centre, which may limit generalizability. The study also used a single set of LIPUS parameters based on previously reported therapeutic ranges,[5,9] and different intensities, frequencies, or treatment durations may yield different clinical effects.

Future research should therefore include larger, multicentre randomized controlled trials with extended follow-up to evaluate the durability of LIPUS-related benefits on implant survival, marginal bone stability, and patient-reported outcomes.[9] Comparative studies versus other adjunctive modalities, such as surface-active biomaterials or pharmacologic agents, would help clarify the relative efficacy and cost-effectiveness of LIPUS in different clinical scenarios.[4,10] Mechanistic investigations integrating advanced imaging and molecular biomarkers in human subjects could further elucidate how LIPUS modulates bone biology at the implant interface and support the refinement of treatment protocols for routine clinical use.[9]

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