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Comparative Study of the Effect of Zinc Supplements Versus Low Level Laser Therapy on Osseointegration of Dental Implant

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ABSTRACT

This study aimed to evaluate and compare the effects of low-level laser therapy (LLLT) and zinc supplementation on the osseointegration of dental implants. Eighteen patients aged 25–45 years were enrolled and randomly allocated into three equal groups: a control group receiving no adjunctive treatment, a laser group treated with LLLT at the implant site, and a zinc group receiving oral zinc supplementation for two months to meet the recommended daily allowance. Peri-implant bone density changes were assessed using digital orthopantomograms obtained immediately after implant placement (baseline), and at 1.5 and 6 months postoperatively. All groups demonstrated a statistically significant progressive increase in bone density along the bone–implant interface during the follow-up period. However, differences were observed in the rate and pattern of bone density changes. The LLLT group exhibited an earlier onset and a more pronounced increase in bone density compared with both the zinc and control groups. In contrast, the zinc and control groups showed slower and more gradual improvements, with no statistically significant difference detected between them. These findings suggest that LLLT significantly enhances peri-implant bone healing and accelerates the osseointegration process around immediately loaded titanium implants. The observed improvement in bone density highlights the biostimulatory effect of laser irradiation and supports its potential use as an effective adjunctive modality in implant dentistry.

Keywords: Dental Implant, Low Level Laser Therapy, Osseointegration, Zinc Supplements

1 Introduction

ORAL implantology is regarded as the quintessential method for oral rehabilitation, offering the most favorable results for dental replacement [1]. The revolutionary effect of dental implants on dentistry is incomparable, offering numerous advantages to different patients, including enhanced aesthetics, better denture retention, and increased self-esteem [2]. Immediate implant loading has gained prevalence and is increasingly welcomed by numerous patients, as it eliminates the necessity for a second surgery and simplifies previsualization through the rapid loading of the implant post-surgery [3].

Uncontrolled continuing bone loss will reduce osseointegration. Biomechanical stress is one of the most significant variables involved in bone loss around well integrated implants [4]. Several attempts have been made to improve this process, one of which involves the use of low-level laser therapy (LLLT) [5].

Low-level laser therapy (LLLT) has been promoted as a modulator of tissue repair, with diverse stimulant properties documented. Nevertheless, the specific mechanism and chemical foundation for such actions remain unknown. Laser therapy has been used to promote soft tissue healing, nerve and bone regeneration, and pain alleviation [6].

Exposure to LLLT may promote bone defect healing both in vivo and in vitro because it enhances the healing environment [6]. The healing procedure is divided into three phases: the substrate phase, the proliferative phase, and the remodeling phase [7]. Laser bio stimulation has been proven to have the highest effect during the proliferative phase [7]. This therapeutic technique has also been proposed for stimulation of osseointegration, suggesting its usage following endosseous implant insertion [8]. LLLT may stimulate the functional attachment of titanium implants to bone and increase bone mineralization, as demonstrated in animal and in vitro investigations [9].

Zinc is an essential trace element with critical importance for human health. An increasing number of research show that zinc plays a vital role in bone tissue formation and homeostasis [10]. Zinc is not only found in bone tissue, but it also has a role in collagen matrix formation, mineralization, and bone turnover. Zinc has been shown to stimulate osteoblast differentiation [11, 12]. Zinc, on the other hand, has been shown to limit the development of osteoclast-like cells and reduce bone resorption by inducing osteoclast death [10, 13].

The introduction of Zn ion (Zn^{2+}) on a titanium dental implant has been shown to boost osteogenic activity and pro-angiogenic capabilities with inhibiting the inflammatory response. Most notably, Zn^{2+} has remarkable anti-bacterial properties [13].

The purpose of this study is to compare the effect of LLLT on the osseointegration of dental implants versus Zinc supplements.

2 Materials and Methods

This research was conducted at two institutions: The National Research Centre (NRC) in Dokki, Giza, and the National Institute of Laser Enhanced Sciences at Beni Sueif University. Due to the exploratory nature of the study, a formal sample size calculation was not performed. A total of 18 patients recruited from the outpatient clinic of the NRC, over the period from 2024 to 2025 and were equally allocated into three groups.

All the study cases were subjected to the following diagnostic procedures.

2.1 *Preoperative Assessment*

2.1.1 History

Any patient revealed signs and symptoms of any systemic diseases, such as hypertension and diabetes mellitus, was excluded in order to standardize the base line conditions for all the patients.

Oral hygiene measures, periodontal history and frequency of periodontal inflammation and gingival bleeding were investigated.

The patients were asked about a history of tempro-mandibular joint (TMJ) disorders, (muscle spasms, clicking, limitation of mouth opening, etc.,) as well as the presence of habits (clenching, bruxism, etc.). The patients who suffered TMJ disorders were excluded from the study.

2.1.2 Clinical Examination

The oral mucosa was evaluated for presence of healthy non-inflamed attached gingiva. The hard and soft tissue structures were evaluated as to both quality and quantity and patients who exhibited severe alveolar bone loss or advanced periodontal disease were excluded.

The jaw relationships were accurately evaluated for the occlusion, teeth alignment, horizontal and vertical relationships of the upper and lower jaws. On the other hand, an extra-oral examination involved the investigation of TMJ disorders, abnormal swellings o + 00X 3. r mandibular shift. The patients who exhibited occlusal discrepancies or TMJ disorders were excluded.

2.1.3 Radiographic Examination

Radiographs were used in conjunction with the clinical examination to ensure the absence of any pathologic bony defects and the verification of complete healing of post-extraction sockets (especially in the intended regions for implantation).

Preoperative digital panoramic radiographs were taken for all the patients in order to evaluate bone height, related vital anatomical structures, bone density (trabeaculation of bone and cortical thickness) which will be elaborated in relative densometric value using specialized software, and to be considered as the patient's own control (Figure 1).

The Cone-Beam Computed Tomography (CBCT) was used to measure length and width of the bone, evaluate the quality of bone available for implant placement and detection of implant site.

Fig. 1. Preoperative panoramic X-ray showing missing

upper first and second premolar and ready for implantation Study models.

Maxillary and mandibular diagnostic study models were fabricated for all the patients and were mounted on simple articulators to evaluate the centric relationship, inter-arch occlusal clearance, occlusal discrepancies as well as the relationship to the opposing dentition. Utilizing the study models, the position of the required implants was evaluated, the implant diameters were determined.

2.2 Patients Grouping

The previous examinations and diagnostic procedures allowed the selection of 18 patients matching the criteria of case selection. The selected subjects were randomly allocated into three equal groups (n = 6 per group) using a computer-generated randomization method. Blinding was implemented, where the radiographic assessor was unaware of group allocation during evaluation.

- Control Group: Six patients were left to progress spontaneously without any interference.
- Zinc Group: six patients adhered to a zinc supplementation schedule designed to fulfill the recommended daily allowance (RDA). The two-month course of treatment commenced four weeks before the surgical procedure and extended for a further four weeks into the recovery period.
- Laser Group: Six patients received LLLT in sessions during the healing phase that followed implant insertion.

2.3 Surgical Phase

2.3.1 Pre-Surgical Stage

This stage involved all the necessary steps and preparations required for implant surgery which involved the following:

- Preparation of the oral cavity: The oral cavity was prepared for surgery. This involved thorough scaling and polishing of teeth. Filling or root canal treatments for the decayed teeth were performed. All the patients were motivated to follow a proper oral hygiene measure by tooth brushing 3-4 times daily followed by 0.2% chlorohexidine HCL mouth wash (Cholorohexidine HCL, The Arab Drug Company, A.R.E) for 1 minute, 3-4 times per day to prevent the plaque accumulation and decreasing gingival inflammation.
- Determination of the implant length and diameter: The CBCT was used to measure length and width of the bone, evaluate the quality of bone available for implant placement and detection of implant site.
- Pre-surgical medications: Oral antibiotics as Augmentin 1 gm (Amoxicillin 875 mg and clavulanic acid 125 mg, GlaxoSmithKline, A.R.E.) (Co-Amoxicillin Clavulanic acid) tablets every 12 hours, was prescribed one and half hours preoperatively and extended for 3 days postoperatively for prophylaxis against infection.
- The patients of group II administrated 11 mg of zinc as zinctron capsules (Cholorohexidine HCL, The Arab Drug Company, A.R.E) once daily as a dietary supplement, starting one month preoperatively and continued for one months after it.
- Preparation of the surgical equipment's and the surgical field armamentarium: The surgical tray was prepared containing:
  - Local anesthetic syringe, carpels and needles.
  - Lancet handle and blade no. 15
  - Muco-periosteal elevator, needle holder, and suture scissors.
  - Minnesota retractor.
  - Threaded 3-0 black silk suture with cutting needle.
  - Predetermined implant diameter and its surgical kit.
- Specific instruments: The implants utilized in this study (Dentium (Cholorohexidine HCL, The Arab Drug Company, A.R.E)) were of the submerged variety, featuring a tapered configuration and a double-threaded design. They incorporated platform switching and underwent surface treatment involving large-grit sandblasting followed by acid etching. All implants measured between 10 to 12 mm in length and 4 to 4.5 mm in diameter.

2.3.2 Surgical Procedure

A topical anesthesia was applied on the oral mucosa before injection, then Middle superior alveolar nerve block anesthesia was applied using Mepecaine L (Mepivacaine hydrochloride 2% with levonordefrin 1:20,000. Alexandria Co. for Pharmaceuticals-Alexandria-A.R.E.) with levonordefrin 1/20,000.

A gingival incision was performed through inter dental papillae of the teeth on both sides of the edentulous area and connected by crestal incision deep to alveolar bone over the edentulous area. The flap was then elevated palatially and slightly buccally by means of a mucoperiosteal elevator.

After the flap was reflected, a trephine bur was used to penetrate the alveolar crest. Drilling was accompanied with copious saline external irrigation, followed by preparation of the recipient site for the placement of the endosseous root form implant system (Figure 2). A low-speed (1500-2000 rpm) high torque hand piece was necessary to prevent excess thermal injury to the bone. The implant site was incrementally expanded using a sequence of progressively larger drills until it reached a diameter slightly less than that of the implant. The implant was then manually threaded into the bone and secured using a ratchet wrench. By gently rotating the ratchet handle clockwise, the implant was gradually advanced and seated into the prepared osteotomy until its collar was positioned just below the crestal bone level. Prior to wound closure, a provisional abutment was placed onto the implant, ensuring proper engagement of the abutment's external hex with the implant's internal hex. The abutment screw was then tightened to securely connect both components. LLLT has been shown to promote the functional integration of titanium implants with bone tissue, as well as to support bone regeneration and mineralization processes 14-16. Then the abutment was prepared by a diamond high speed stones to adjust the height of the abutment. Following irrigation of the surgical site with sterile saline, the flap was carefully repositioned and secured using interrupted 3-0 black silk sutures. A provisional crown was then fabricated, adjusted for proper fit and contour, smoothed, polished, and temporarily cemented onto the abutment. Care was taken to ensure the temporary restoration was free of occlusal contact with the opposing maxillary dentition.

The final prosthesis (porcelain fused to metal) was delivered for all patients six months post-operatively. After removing the temporary crowns and freeing the abutments, the state of gingival health was evaluated. Any patient showed any degree of gingival inflammation was instructed to fulfill regular tooth brushing and chlorhexidine mouth wash protocols. Then the final abutment was screwed, and prosthetic part was fabricated (Figures 3 and 4).

2.4 Laser Application

In the present investigation, a low-level gallium arsenide laser emitting at 904 nm was employed in conjunction with a biomodulating handpiece. The device was configured with the following parameters: output power of 20 mW, spot diameter 4 mm and exposure time 30 sec during which laser probe applied to the buccal surface with a dose 4.7 J/cm^2 [17].

Fig. 2. A photograph showing flap elevation inside the implant bed.

Fig. 3. A photograph showing screwing the final abutment into the implant.

Fig. 4. A photograph showing the final prosthesis (porcelain fused to metal).

During application, the laser probe was maintained in gentle contact with the soft tissues and oriented toward the implant area. To ensure uniform coverage, the probe was moved in a continuous, slow circular motion over the target surface, thereby facilitating complete exposure of the area to the laser beam (Figure 5). Each patient received a total of nine sessions conducted on alternate days, starting from the second day after surgery. The cumulative energy delivered over the entire treatment course amounted to 42.3 J [17].

Fig. 5. A photograph showing Laser application at the implant site.

2.5 Radiographic Assessment

Osseointegration was assessed indirectly through radiographic evaluation of peri-implant bone density using digital panoramic radiographs and Digora software.

2.5.1 Exposure Parameters

Each case under investigation was subjected to a digital panoramic examination using (PLANMECA) to produce a panoramic radiograph with magnification [17, 18]. The milliampere and the exposure time values were (12 mA) and (12 secs) respectively, while the voltage range was (80 Kv) according to the standard.

The patients were positioned according to the standard procedure [17].

2.5.2 Radiographic Schedule

Following the surgery, all the patients were asked to recall according to the following schedule for imaging procedures. Baseline digital orthopanographs were taken postoperatively in the same day of surgery, the next were taken 1.5 months postoperatively and the final digital orthopanographs were taken 6 months postoperatively just after the final prosthesis had been delivered.

2.5.3 Measurement of Bone Density

Bone density was measured by Digora*, soft-ware system, around the implant (mesial, distal and apical) in each group.

All of the digital panoramic radiographs were introduced to Digora software, linear measurement system, that achieve computer analysis and elaborates relative densitometric values for the bone surrounding the implants and statistical analysis were done and compared.

Bone density around the implants was assessed using Digora software through a standardized protocol. For each implant, three reference lines were established: one on the mesial side, one on the distal side, and one apical to the implant. The mesial line was traced from the level of the first thread down to the implant apex, running parallel and adjacent to the thread contours. Similarly, the distal line followed the same path along the opposite side. The apical line was drawn horizontally between the mesial and distal aspects of the implant, just beneath its tip. Bone density values were recorded along each of these lines, and the average of the three measurements was used for analysis.

2.6 Statistical Analysis of Data

Quantitative data were summarized using mean and standard deviation (SD). The assumption of normality was verified through the Kolmogorov–Smirnov and Shapiro–Wilk tests, both of which indicated that the data followed a normal distribution. For comparisons among three or more related groups, repeated measures analysis of variance (ANOVA) was employed. Paired sample t-tests were used to assess differences between two related groups. When analyzing differences among three or more independent groups, one-way ANOVA was applied, with Tukey's post hoc test used for subsequent pairwise comparisons. To explore potential interactions between variables, two-way ANOVA was conducted. A significance threshold of $p \leq 0.05$ was adopted for all statistical tests. All analyses were performed using IBM® SPSS® Statistics, version 20, for Windows.

2.7 Ethical Considerations and Permissions

All procedures involving human subjects were performed in accordance with the ethical standards set by the World Medical Association (Declaration of Helsinki). Ethical approval for this study was granted by the High Research Ethics Committee, operating under the Quality Assurance Unit of the Faculty of Dentistry, Beni Suef University (Approval No. HREC BSU/026211). Prior to participation, all patients provided written informed consent after receiving a comprehensive explanation of the potential benefits and risks involved.

3 Results

3.1 Bone Density Results

3.1.1 Effect of Area

In the control group, there were no statistically significant differences among the mesial, distal, and apical measurements at any of the evaluated time points. Immediately after surgery, the comparison showed no statistically significant difference ($p = 0.040$), with the highest mean value observed in the mesial region, followed by the distal region, while the apical region demonstrated the lowest mean value. Similarly, after 1.5 months, no statistically significant difference was detected among the three regions ($p = 0.060$), maintaining the same pattern of mean values, with mesial being the highest, followed by distal and then apical. After 6 months, the differences among mesial, distal, and apical regions remained statistically non-significant ($p = 0.152$), and the mesial region continued to show the highest mean value, followed by the distal region, with the apical region exhibiting the lowest mean value.

In the zinc group, no statistically significant differences were observed among the mesial, distal, and apical measurements at any of the assessed time points. Immediately after surgery, the comparison revealed no statistically significant difference ($p = 0.21$), with the highest mean value recorded in the mesial region, followed by the distal region, while the apical region showed the lowest mean value. At 1.5 months, the differences among the three regions remained statistically non-significant ($p = 0.432$), with the same distribution pattern of mean values, where the mesial region exhibited the highest mean value, followed by the distal and apical regions. After 6 months, no statistically significant difference was detected among the mesial, distal, and apical regions (p = 0.050), and the mesial region continued to demonstrate the highest mean value, followed by the distal region, whereas the apical region showed the lowest mean value.

In the laser group, no statistically significant differences were observed among the mesial, distal, and apical measurements across all evaluated time intervals. Immediately after surgery, the comparison revealed no statistically significant difference among the three regions (p = 0.40), with the highest mean value recorded in the mesial region, followed by the distal region, while the apical region exhibited the lowest mean value. During the immediate to 1.5-month interval, the differences among the mesial, distal, and apical regions remained statistically non-significant (p = 0.682); however, the highest mean value was observed in the apical region, followed by the mesial region, whereas the distal region showed the lowest mean value. For the immediate to 6-month interval, no statistically significant difference was detected among the three regions (p = 0.304), with the mesial region demonstrating the highest mean value, followed by the distal region, while the apical region again showed the lowest mean value, see Figure 6-8 and Tables 1-3.

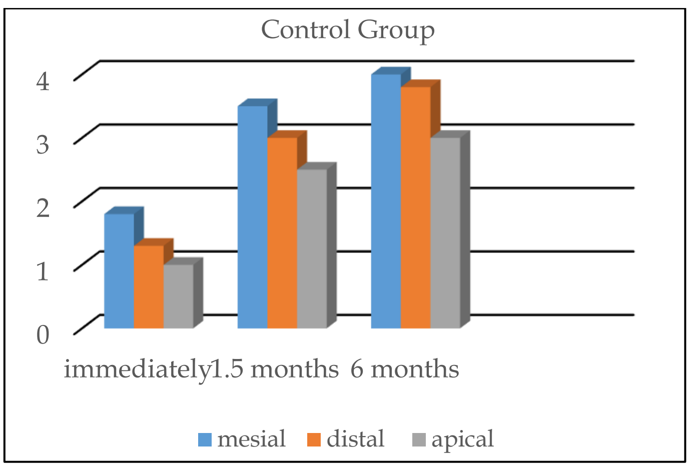

Fig. 6. The effect of area on bone density for different Control groups.

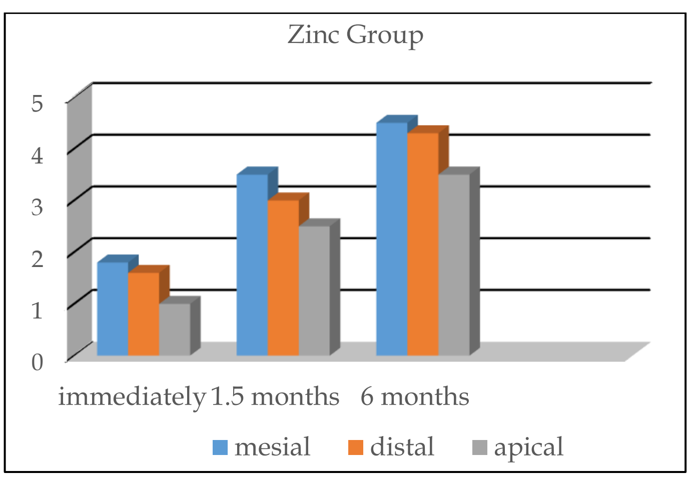

Fig. 7. The effect of area on bone density for different zinc groups.

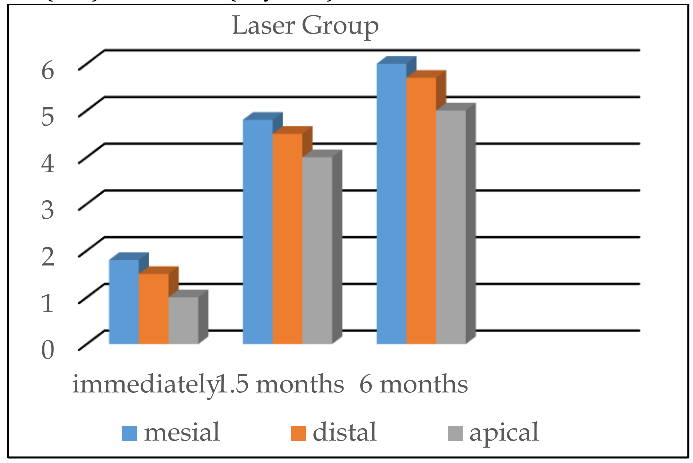

Fig. 8. The effect of area on bone density for different Laser groups.

3.2 *Bone Density Results Regardless of Area*

3.2.1 Effect of Time

In the control group, a statistically significant difference was observed between the 1.5-month and 6-month time points (p < 0.001). The highest mean value was recorded at 6 months, whereas the lowest mean value was observed at 1.5 months.

Similarly, in the zinc group, there was a statistically significant difference between the 1.5-month and 6-month measurements (p < 0.001). The highest mean value occurred at 6 months, while the lowest mean value was found at 1.5 months.

In the laser group, a statistically significant difference was also detected between the 1.5-month and 6-month time intervals (p < 0.001). The highest mean value was observed at 6 months, whereas the lowest mean value was recorded at 1.5 months.

3.2.2 Effect of Groups

Immediately after surgery, no statistically significant difference was observed among the laser, control, and zinc groups (p > 0.05).

At 1.5 months, a statistically significant difference was detected among the laser, control, and zinc groups (p < 0.001). Pairwise comparisons revealed a statistically significant difference between the laser group and each of the control and zinc groups (p < 0.001), while no statistically significant difference was found between the control and zinc groups (p = 0.309). The highest mean value was recorded in the laser group, followed by the zinc group, whereas the lowest mean value was observed in the control group.

Similarly, at 6 months, a statistically significant difference was observed among the laser, control, and zinc groups (p < 0.001). Further analysis showed statistically significant differences between the laser group and each of the control and zinc groups (p < 0.001), with no statistically significant difference between the control and zinc groups (p = 0.309). The laser group demonstrated the highest mean value, followed by the zinc group, while the control group showed the lowest mean value (Table 4).

Table 1. The values of bone density change of different Control groups.

Variables	Control								
	Immediately			1.5 months			6 months		
	Mean	SD	%	Mean	SD	%	Mean	SD	%
Mesial	4.34	0.87	3.43	6.17	1.28	4.12	12.14	2.81	8.08
Distal	3.54	0.23	2.23	4.32	2.13	3.16	10.46	1.75	7.37
Apical	2.34	0.12	2.15	2.91	1.67	2.18	9.11	1.04	6.56
p-value	0.040*			0.060ns			0.152ns		

Table 2. The values of bone density change of different zinc groups.

Variables	Zinc Group								
	Immediately			1.5 months			6 months		
	Mean	SD	%	Mean	SD	%	Mean	SD	%
Mesial	5.45	2.32	4.56	6.94	3.99	5.04	14.21	4.95	9.75
Distal	5.34	2.01	4.38	6.09	2.84	4.64	11.34	4.11	8.32
Apical	4.12	2.01	3.26	5.66	2.87	4.27	10.40	3.49	7.48
p-value	0.21ns			0.432ns			0.050ns		

Table 3. The values of bone density change of different Laser groups.

Variables	Laser								
	Immediately			1.5 months			6 months		
	Mean	SD	%	Mean	SD	%	Mean	SD	%
Mesial	4.45	2.32	4.56	11.60	4.87	7.97	21.99	5.48	14.25
Distal	4.34	2.01	4.38	10.51	4.33	7.43	21.74	3.56	14.43
Apical	3.12	2.01	3.26	12.57	6.23	8.75	18.90	5.91	12.66
p-value	0.04*			0.682ns			0.304ns		

Table 4. The values of bone density of different groups.

Variables	Bone density									
	Laser			Zinc			Control			p-value
	Mean	SD	%	Mean	SD	%	Mean	SD	%	
Imm-1.5m	11.56	5.10	8.05	6.23	3.21	4.65	4.80	2.46	3.49	<0.001*
Imm-6m	20.88	5.11	13.78	11.98	4.40	8.52	10.90	2.58	7.64	<0.001*
p-value	<0.001*			<0.001*			<0.001*			

*: significant ($p < 0.05$), ns: non-significant ($p > 0.05$).

4 Discussion

In implant dentistry, osseointegration has become the admitted standard for successful dental implants. Yet, impaired healing, infection, and overload are well known causes of failure of these devices 18. Osseointegration of an implant is achieved when no progressive relative motion occurs at the interface between the implant surface and the surrounding bone tissue with which it maintains direct contact [19].

The human alveolar bone reaches its maximum level approximately ten years after puberty which remains nearly constant until the fourth decade and thereafter, the bone mass begins to gradually decrease [18]. Moreover, 16 accused that the amount of bone tissue is diminished, and bone becomes weaker as its ages. The authors considered that uncoupling of osteoblastic and osteoclastic activity in favour of osteoclasts is responsible for Age-associated bone loss. Therefore, the age of the patients selected in the current study ranged from (25 – 40) years.

Smoking was accused for being one of the most serious risk factors that contribute to implant failure [19]. Moreover, it was assumed that there is a correlation between smoking and bone quality that jeopardize the quality of the bone formed around titanium implants [20, 21]. Thus, all the selected patients were non-smokers.

Numerous studies reported higher early implant failures for both mandibular and maxillary areas in posterior regions [22-25]. This may be due to several conditions existing in posterior sites, like barely enough bone volume, inferior bone quality and elevated functional forces [26]. The cortical layer of both jaws has tendency to be thinner and more porous posteriorly. Moreover, posterior implants have to withstand the heaviest load and are mostly short as a result of deficient volume of available bone (the maxillary sinus and inferior alveolar nerve are the main anatomical limitations) [23, 27]. In the present study, the maxillary first premolar area was selected as a standard site for implant placement due to its clinical relevance. This region is generally associated with lower bone density and a higher risk of implant failure compared to anterior areas of the jaw. Furthermore, the application of immediate or early loading protocols in this region may contribute to elevated failure rates. This is likely because premature occlusal forces during the healing phase could interfere with the bone's regenerative capacity, potentially compromising the repair of the bone-implant interface [28]. The selection of the maxillary premolar region as a standardized site was considered to introduce an additional level of difficulty when evaluating the effectiveness of methods aimed at enhancing or accelerating osseointegration.

Micronutrients play an essential role in supporting skeletal development and maintaining bone integrity throughout life. Several minerals contribute directly to the formation and structural stability of hydroxyapatite crystals, which are the primary mineral component of bone. In addition, other nutrients function indirectly by acting as enzymatic cofactors or by modulating cellular processes involved in bone metabolism [29, 30]. Trace elements, such as iron, zinc, copper, calcium, phosphorus and magnesium, modify bone formation and metabolism as they are necessary for bone growth and development because these elements interact with bone matrix and influence bone metabolism 31, for these reasons we choose to use Zinc to see its effects on osseintegration process.

The present study employed the Dentium implant system, as its surface undergoes sandblasting with large-grit particles followed by acid etching (SLA). This treatment enhances surface roughness, thereby increasing the contact area at the bone-implant interface and supporting effective osseointegration [32]. This go in accordance to [33] who concluded there is an optimal range of surface roughness that varies from 1.0 to 2.0 μm (moderately rough surfaces as those obtained by grit blasting and acid etching). Within this range of surface roughness, a stronger bone response and better clinical results could be achieved. Roughness greater than 0.2 μm as in titanium plasma sprayed surfaces increase the incidence of peri-implantitis and ionic leakage.

Implant length and diameter selection is considered as an important factor in determining the prognosis of immediately loaded implants. Fifty percent failure rate after ten years of immediate loading of implants less than 10 mms in length was recorded by [34]. The authors recommended the utilization of implants more than 14 mms in length and 4 mms in diameter when immediate loading is considered. Accordingly, the largest possible implant dimensions were always chosen with regard to both length and diameter; most of the inserted implants had lengths of 10 or 12 mms and diameter of 4 or 4.5 mms; the smallest inserted implant was of 10 mms length and 4.5 mms diameter.

Numerous novel approaches are currently under investigation to improve bone metabolism and expedite the bone healing process [35]. To date, a range of strategies, including bone grafting, the application of growth factors, platelet-rich fibrin, low-intensity pulsed ultrasound, and LLLT, have been suggested as means to support and accelerate bone regeneration [36-38].

LLLT has recently garnered significant research interest for its role in enhancing wound healing and promoting bone regeneration. This therapeutic approach operates through the biostimulatory effects of monochromatic light on biological tissues. A growing body of evidence highlights its capacity to modulate various biological processes, particularly in accelerating wound repair [39, 40] and stimulating collagen production [41, 42], modulation of inflammation and relief of pain [43, 44].

It has been reported that the LLLT is able to increase osteoblastic activity [45] accelerate cell proliferation [46], organize collagen fibers, change mitochondrial and intracellular adenosine triphosphate level [47], promote angiogenesis [48, 49] and enhance osseointegration [8, 50, 51].

Tuby et al. [52] concluded LLLT irradiation is supposed to improve bone matrix production. That was in agreement [53] as the authors reported that the bones subjected to (LILT) showed increased volume as well as apposition rates. It also accelerates the healing process when applied directly over the bone tissue lesion [54].

This study conducted on eighteen patients who were divided into three equal groups, six patients each; Laser group, where patients were subjected to low intensity diode laser with 904 nm using contact mode, continuous wave (CW), 20 mw output power, spot diameter 4 mm and exposure time 30 sec during which laser probe applied to the buccal surface with a dose 4.7 J/cm^2. The zinc group received zinc supplementation for a two-month period to meet the recommended dietary allowance (RDA). This supplementation protocol commenced one month prior to the scheduled surgical procedure and continued for one month postoperatively. The control group, by contrast, received neither LLLT nor zinc supplementation throughout the study period.

In this investigation, a low-level gallium arsenide laser emitting at 904 nm was employed to promote osseointegration and improve peri-implant bone density through a regenerative protocol. While LLLT has been widely explored across various medical and dental fields for its effects on bone tissue using wavelengths between 670 and 1,064 nm, research specifically targeting the 904 nm wavelength remains limited. Commonly applied wavelengths in the literature include 670, 690, 780, 830, and 1,064 nm [55, 56].

Previous work has supported the use of 904 nm infrared laser for bone applications. This wavelength falls within the near-infrared spectrum and is characterized by a low absorption coefficient, allowing for deeper tissue penetration. As a result, it may contribute to enhanced tissue resistance and improved bone mineralization [57, 58].

In the present study, a continuous-wave gallium arsenide laser (904 nm) was applied at an output power of 0.02 W for 30 seconds per session. A total of nine sessions were conducted on alternate days, starting from the second day after surgery. This regimen was informed by earlier findings indicating that exposure durations between 30 and 120 seconds yield the most pronounced biomodulatory effects [59].

The energy density used here was 4.7 J/cm², selected based on histological evidence from a prior study involving 830 nm laser therapy in a rat model of bone defect repair. That research demonstrated accelerated healing, enhanced bone formation, and the presence of organized collagen fibers surrounding graft material within the defect site by day 15 post-surgery [52].

Laser irradiation has been shown to stimulate early-phase proliferation of fibroblastic, osteoblastic, and mesenchymal cells. Following injury, bone regeneration typically begins in vascularized zones under hypoxic conditions, and laser application appears to accelerate this process by promoting bone matrix formation [58]. Evidence suggests that the beneficial effects of LLLT are most prominent within the first week after surgery, a pattern consistent with the outcomes observed in the current study [60].

The findings of this study demonstrated no statistically significant variation among the three bone regions, mesial, distal, and apical, across all experimental groups, as presented in Tables 1-3. These observations are consistent with earlier research by [61], which reported equivalent bone loss on both the mesial and distal aspects of implants after a six-month follow-up period. In contrast, a statistically significant cumulative effect over time was observed in bone density across all bony zones surrounding the implants, as detailed in Table 4. This outcome supports previous work conducted on White New Zealand rabbits, where implants coated with eicosatetraenoic acid were found to promote osteoconduction and improve implant integration with adjacent bone tissue [62]. Furthermore, the findings are in agreement with a study by [63], which concluded that zinc supplementation facilitates bone regeneration in the vicinity of dental implants.

Although all experimental groups demonstrated a statistically significant rise in mean bone density across the three zones throughout the follow-up period, the rate of increase was notably higher in the laser-treated group. In this group, the increase occurred earlier and was consistently maintained in all three zones, in contrast to the slower and more delayed bone density improvements observed in the zinc and control groups (Table 4). This outcome may be attributed to laser-induced angiogenesis, improved vascularization, and enhanced tissue perfusion, which likely facilitated the delivery and accumulation of essential micronutrients and minerals in the wound area. Consequently, this process promoted greater mineral deposition and accelerated gains in bone density within a relatively short timeframe. Additionally, previous studies have shown that LLLT enhances cellular proliferation, bone nodule formation, and alkaline phosphatase (ALP) activity [64, 65]. Evidence also supports the role of LLLT in improving the functional attachment of titanium implants to bone and in promoting bone healing and mineralization [66, 67].

In the present study, osseointegration was assessed indirectly using radiographic bone density measurements. Although this method provides useful information regarding peri-implant bone changes, it does not represent a direct or comprehensive assessment of osseointegration. More reliable clinical and biomechanical methods, such as resonance frequency analysis (implant stability quotient), Periotest measurements, and evaluation of marginal bone levels, were not included in this study. Therefore, the findings should be interpreted with caution, and future studies incorporating multiple assessment tools are recommended for a more accurate evaluation of osseointegration.

The effect of zinc supplementation in the present study should be interpreted with caution. Baseline serum zinc levels were not assessed, and participants were not screened for zinc deficiency. In addition, dietary zinc intake and patient compliance with supplementation were not monitored. These factors may have influenced the observed outcomes and could explain the lack of significant effect in the zinc group. Therefore, further studies controlling for baseline zinc status and ensuring compliance are recommended.

The relatively small sample size represents a limitation of this study. Therefore, the results should be interpreted with caution, and further studies with larger sample sizes are recommended to confirm these findings.

5 Limitations of the Study

The present study has several limitations that should be acknowledged. First, the relatively small sample size may limit the generalizability of the findings. Second, the follow-up period was relatively short, which may not fully reflect the long-term effects of low-level laser therapy and zinc supplementation on implant osseointegration. Additionally, bone density assessment was performed using panoramic radiographs, which provide less accuracy and sensitivity compared with cone beam computed tomography (CBCT) or histological evaluation. Therefore, future studies with larger sample sizes, longer follow-up durations, and more advanced assessment modalities are recommended to validate and expand upon the current findings.

6 Conclusion

From the results of the present study, it can be concluded that low-intensity laser irradiation represents a safe and effective method for accelerating bone healing around titanium implants. Regardless of laser application, bone density surrounding immediately loaded dental implants in all studied groups showed a significant improvement over time. However, bone healing and osseointegration progressed more uniformly and at a faster rate in the laser-treated group compared with the zinc and control groups. Further improvements to this study could be achieved by evaluating additional techniques and therapeutic modalities that may enhance the osseointegration process.

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