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ORIGINAL ARTICLE

Stability of dental implants after irradiation with an 830-nm low-level laser: a double-blind randomized clinical study

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Abstract Little is known about the benefits of low-level laser therapy (LLLT) on improvement of stability of dental implants. The aim of this randomized clinical study was to assess the LLLT effect on implants stability by means of resonance frequency analysis (RFA). Thirty implants were distributed bilaterally in the posterior mandible of eight patients. At the experimental side, the implants were submitted to LLLT (830 nm, 86 mW, 92.1 J/cm^2, 0.25 J, 3 s/point, at 20 points), and on the control side, the irradiation was simulated (placebo). The first irradiation was performed in the immediate postoperative period, and it was repeated every 48 h in the first 14 days. The initial implant stability quotient (ISQ) of the implants was measured by means of RFA. New ISQ measurements were made after 10 days, 3, 6, 9, and 12 weeks. The initial ISQ values ranged from 65–84, with a mean of 76, undergoing a significant drop in stability from the 10th day to the 6th week in the irradiated group, and presenting a gradual increase from the 6th to the 12th week. The highest ISQ values were observed on the 10th day in the irradiated group, and the lowest in the 6th week in both groups. Under the conditions of this study, no evidence was found of any effect of LLLT on the stability of the implants when measured by RFA. Since high primary stability and good bone quality are of major relevancy for a rigid bone–implant interface, additional LLLT may have little impact macroscopically.

Keywords Bone repair · Implants · Laser therapy · Primary stability

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Introduction

In 1969, implant dentistry took on a new dimension when Brånemark described the concept of osseointegration. One of the disadvantages in the original protocols for implant placement was the time required for osseointegration to occur before the prosthesis is placed. However, the development of new implant surfaces and clinical techniques has enabled a considerable reduction of the initial healing period. Thus, authors proposed variations of the technique for bringing the implant into function and reduce the osseointegration time, by altering the texture of the titanium implant surface [1–3].

The use of low-level lasers has been suggested as another way of accelerating and improving the bone tissue healing process [4]. Laser light irradiation has been applied in the medical field and has biostimulatory effects on wound healing, collagen synthesis, and fibroblast proliferation [5–7]. In addition, laser light appears to increase mitochondrial respiration and adenosine triphosphate (ATP) synthesis [8, 9].

Many studies indicate that bone irradiated mostly with infrared wavelengths shows increased osteoblastic proliferation, collagen deposition, and bone neoformation when compared to non-irradiated bone [10–13]. Little data exist concerning these effects on the osseointegration process of implants [14–17].

At the present moment, the quality at the bone–implant interface continues to be the target of studies and research. The importance of primary stability in implant placement for long-term success is well known in the literature. Clinical methods like implant percussion, radiography, insertion torque, and manual reverse torque, are questionable methods regarding their effectiveness for measuring the quality of implant osseointegration [18]. Invasive biomechanical tests such as removal torque and histomorphometric analysis measurements can provide important information regarding implant rigidity in the bone during a certain period of the osseointegration process and can accurately assess morphological changes at the bone–implant interface, respectively; however, these methods demand sacrifice of the implant and preclude clinical follow-up afterwards, which is unfeasible for monitoring clinical changes at the bone–implant interface [19, 20].

Other techniques, such as the Periotest and resonance frequency analysis (RFA), aim to provide an objective and reliable measurement of implant stability and osseointegration that is non-invasive and does not injure the bone–implant interface [21–24].

The RFA technique has extensively been used in experimental and clinical research for the last 10 years for assessing primary stability, determining the adequate period of osseointegration before loading the implant, verifying whether sufficient stability has been attained in second-stage surgery, following-up the stability during the osseointegration process, as well as monitoring high-risk implants [25–30].

Since no report exists in the literature concerning the LLLT effects on the osseointegration process of implants using a non-invasive technique as RFA, the aim of this randomized double-blind clinical study was therefore to investigate whether stability (ISQ values) of titanium implants placed in the posterior mandibular region of partially edentulous patients, can be enhanced by LLLT during the osseointegration process when measured by means of RFA.

Patients and methods

This study was conducted at FUNDECTO, at the School of Dentistry of the University of São Paulo, Brazil, after being previously approved by the Human Research Ethics Committee (Protocol #243/04). All patients signed an informed consent form, in accordance with the Helsinki Declaration of 1975, as revised in 2002.

Patients' selection

From 227 patients, 19 eligible participants were recruited by self-selection through advertisements from January until November 2005. Seven patients did not fulfill the inclusion criteria, three refused to participate, and we lost contact with one. For patients' selection and treatment planning, panoramic and periapical radiographs of the area were required, followed by clinical intraoral examination.

Eight healthy adults patients, two males and six females (mean age: 36 years, range: 20–55 years) participated in this study. The patients attended clinic visits from November 2005 (baseline) until February 2006 (final outcome assess). The follow-up period during the study for each patient was 3 months. One follow-up per year is still performed until the present date.

The patients were selected in accordance with the following inclusion criteria: non-smokers, absence of systemic alterations, absence of parafunctional habits (bruxism and/or tooth clenching), sufficient bone volume in the posterior mandibular region to receive implants of 3.8 standard diameter and length of 11 mm, without requiring bone reconstruction procedures, need of bilateral reconstruction in the posterior mandibular region, no contraindication to the systemic medication protocol and good oral hygiene. Patients were not admitted to this study if they had been submitted to bone reconstruction procedures or no commitment to return for follow-up.

The selected patients were then submitted to the surgical and prosthetic planning, followed by periodontal evaluation, cast models and mouth preparation, in order to be able to receive the implants in healthy conditions.

The surgical procedure was performed by a single experienced calibrated surgeon. A trained calibrated operator, who was unaware of which side would be irradiated, performed the ISQ measurements after implants' placement and during the study. Another calibrated operator, who randomly determined the side to be irradiated by the flip of a coin, performed the laser irradiation and the other side remained as control. The information was maintained in secret by this operator until de end of the analysis. The patients were blinded to group assignment, since the irradiation was simulated in one of the sides.

Implants

The sample size was determined with a significance level of $\alpha=0.05$; a sample power of 80%, Student's t test for repeated measurements to detect differences of 10% between mean ISQ of treatments, and a standard deviation difference of 7. Considering these parameters, ten implants per treatment was considered our initial sample size.

A total of 30 implants ($n=30$) XiVE-S (Dentsply Friadent, Mannheim, Germany) were placed in eight patients following a split-mouth design. The placebo group consisted of 14 implants ($n=14$) and the laser group consisted of 16 implants ($n=16$). Between 2 and 5 implants were inserted per patient, distributed bilaterally in the posterior mandible and in agreement with the prosthetic requirement and indication. Five patients received four implants (two at each side), one received five implants (two in one side and three in the other side) one received three implants (two in one side and one in the other side) and one received two implants (one at each side).

Surgical technique

The systemic medication protocol was as follows: amoxicillin 500 mg taken orally every 8 h for 7 days, starting 1 day before surgery, diclofenac sodium 50 mg taken orally every 8 h for 3 days, and acetaminophen 750 mg taken orally every 6 h for 2 days.

Antisepsis of the peribucal region was performed with povidone iodine, and the patients performed mouthwashing with 0.12% chlorhexidine gluconate solution (Periogard®, Colgate) for 1 min. Mouthwashing was performed twice a day for 2 weeks after surgery.

Local anesthesia was induced by infiltration with 3% mepivacaine and 1:100,000 of epinephrine (DFL, São Paulo, Brazil). After crestal incision, a mucoperiosteal flap was elevated. All the implants were inserted by an experienced calibrated surgeon according to a strict protocol following the manufacturer's instructions (XiVE surgical tray, Dentsply Friadent, Mannheim, Germany). Implant placement was performed up to the bone level using a torque driver (Nobel Biocare DEC 600, Göteborg, Sweden) under cooling with physiological solution and with a torque of over 40 Ncm (Fig. 1a).

Resonance frequency analysis

The stability measurements were taken using the Resonance Frequency Analyzer (Osstell model 6.0, Integration Diagnostics, Göteborg, Sweden). The transducer (type F10L5, Integration Diagnostics, Göteborg, Sweden) was fitted with a torque of 10 Ncm measured with a manual torque meter (Conexão, São Paulo, Brazil). The transducer had a perpendicular orientation to the alveolar crest and its upright beam was placed on the lingual side (Fig. 1b).

For the determination of the device measurement repeatability under identical experimental conditions and enhance the quality of measurements, the transducer was tightened and loosened three times, and three measurements were done for each tightening. From these nine measurements, a more representative mean was obtained of the stability value of each implant.

The healings abutments were placed and the implants were allowed to heal transmucosally, thus facilitating the resonance frequency measurements afterwards. After 10 days, 3, 6, 9, and 12 weeks, new ISQ measurements were taken to verify the development of implant stability in these periods.

Low-level laser therapy

The side to be irradiated (LS, laser side) was randomly assigned by the flip of a coin, with the other side (placebo) remaining as control but with laser simulation (CS, control side).

The irradiations were performed with a gallium-aluminum-arsenide (GaAlAs) diode low-level laser with

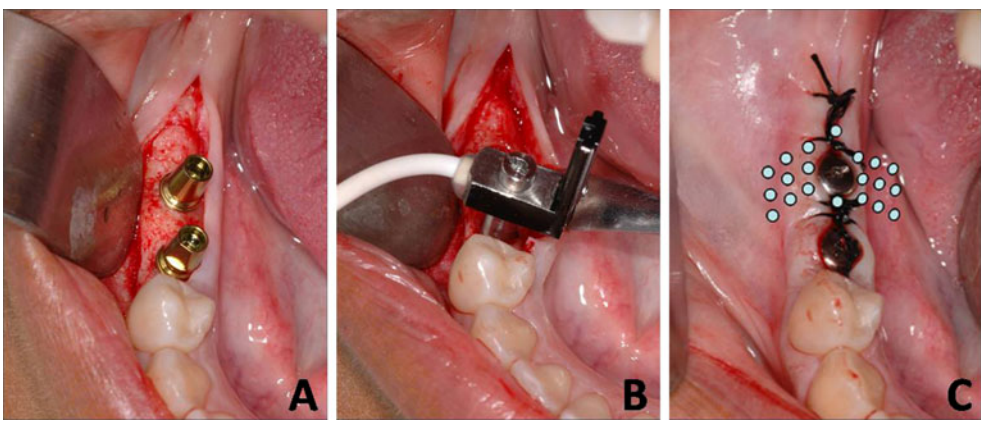

Fig. 1 **a** Implant placement. **b** Transducer fitted intraoral. **c** Points of irradiation per implant

continuous emission of 830-nm wavelength (Thera Lase, DMC, São Carlos - SP, Brazil). The laser power of 86± 2 mW was measured before each irradiation by a power/energy meter (Fieldmaster, Coherent, Auburn, CA, USA). The laser beam diameter was verified by the knife-edge method, as described by Argüello et al. (1995) [31] and Bachmann et al. (2003) [32], so the laser spot size was 0.0028 cm^2, resulting in a calculated energy density of 92.1 J/cm^2, and a energy of 0.25 J per point. The irradiation time was 3 s per point through a punctual technique, in contact. The total delivered energy was 5 J, equally divided by 20 irradiation points.

On the experimental side, the first irradiation was performed in the immediate postoperative period at 20 points (Fig. 1c): nine points at the vestibular region, nine at the lingual, one at the distal, and one at the mesial region of the implant. The irradiations were repeated strictly every 48 h for the first 14 days (seven irradiations).

Periapical radiographs were obtained as control. After 12 weeks, the implants received single cemented crowns. Clinical and radiographic control was maintained after prostheses installation.

Statistical analysis

An intention-to-treat analysis of variance (ANOVA) for repeated measurements and Bonferroni test were used to assess statistically significant differences among the ISQ means between and within the groups during the osseointegration process. The same analysis was adopted for difference in ISQ percentage (dif. % ISQ). Statistical significance was set at 0.05.

Results

All of the eight patients enrolled in this study received the intended treatment and completed the study protocol. The laser group consisted in 16 implants randomly assigned (n=16), while the control group consisted of 14 implants (n=14). In the laser group, 15 implants received the allocated intervention and were included in the analysis; one did not receive the allocated intervention due to inadequate primary stability during insertion and was allowed to osseointegrate submerged; a second implant rotated in the third week while tightening the transducer screw.

Twenty-nine implants were clinically stable, randomly allocated to interventions. All the implants that were followed-up were considered for the analysis. A clinical and radiographic control was performed after 6 months in order to evaluate the implants conditions. All implants were clinically stable and free of symptoms; no pathological marginal bone loss was observed radiographically around the implants. The implants' success rate was 100%.

The mean ISQ values and the mean ISQ difference percentage (dif. % ISQ) are presented in Tables 1 and 2, respectively. The behaviors of the ISQ means, dif. % ISQ in time, in the CS and LS, are also shown in Figs. 2 and 3.

Figure 2 shows that at the LS, the maximum stability is attained 10 days after implant placement, and falls until the 6th week and increasing again by the 12th week. In the CS, the mean ISQ grows up to the 3rd week, falls in the 6th week, and then begins to grow again.

Figure 3 shows that the dif. % ISQ means are higher and positive in the LS 10 days after implant placement, reflecting an increase in ISQ at this time in comparison with initial time; as from the 3rd week the mean differences are negative, which suggests a diminished stability in comparison with the initial time. In the CS, the mean differences are all positive, indicating that in this group, the stabilities at the times 10 days, 3, 6, 9, and 12 weeks are higher than at the initial time.

Intention-to-treat analysis of variance for repeated measurements (29/30) for the ISQ means showed interaction between treatment and time (p=0.025) and paired comparisons (Bonferroni test) revealed significant differences between ISQ means at 10 days and 6 weeks in the LS (p=0.028), the mean at 10 days being higher than the one at 6 weeks. No statistically significant differences were detected among the ISQ means in the two groups for each of the six observations.

Same intention-to-treat analysis of variance for repeated measurements (29/30) for the dif. % ISQ means was performed and an interaction effect between time and treatment was detected (p=0.018), and paired comparisons (Bonferroni test) revealed significant differences between dif. % ISQ means at 10 days and 6 weeks in the LS (0.048),

Table 1 Descriptive statistics for ISQ and number of implants (N) per side (C, control and L, laser) and observation time

Time	Side	n	ISQ mean	Standard deviation
Insertion	C	14	75.7	5.6
	L	15	77.4	3.4
10 days	C	14	76.2	4.6
	L	15	78.9	3.7
3 weeks	C	14	76.9	3.5
	L	15	76.8	4.6
6 weeks	C	14	76.3	2.3
	L	15	75.5	4.0
9 weeks	C	14	77.7	3.5
	L	15	76.2	4.9
12 weeks	C	14	78.4	3.0
	L	15	76.3	4.1

Table 2 Descriptive statistics for dif. % ISQ and number of implants (N) per side (C, control and L, laser) and observation time

Time	Side	*n*	ISQ mean	Standard deviation
10 days	C	14	1.0	7.9
	L	15	2.0	3.6
3 weeks	C	14	1.8	6.3
	L	15	-.5	4.7
6 weeks	C	14	1.2	7.5
	L	15	-2.1	4.7
9 weeks	C	14	3.1	7.6
	L	15	-1.3	7.1
12 weeks	C	14	3.9	7.0
	L	15	-1.2	6.5

the mean at 10 days being higher than the one at 6 weeks. No statistically significant differences were detected among the ISQ means in the two groups for each of the six observations.

Also, the mean difference between the groups (estimated size effect) in each time of observation was estimated with a confidence interval of 95%. The intervals are presented in Table 3. It can be noticed that the zero is included in the interval in each time, so the differences are not considered significant.

Discussion

A number of experimental and clinical studies of LLLT have reported promising outcomes regarding improvement of the bone-healing process; however, little data is available concerning these effects on implant osseointegration.

The GaAlAs laser with an 830-nm wavelength was selected on the basis of successful results obtained on fibroblasts and also on osteoblasts, both in vitro and in vivo

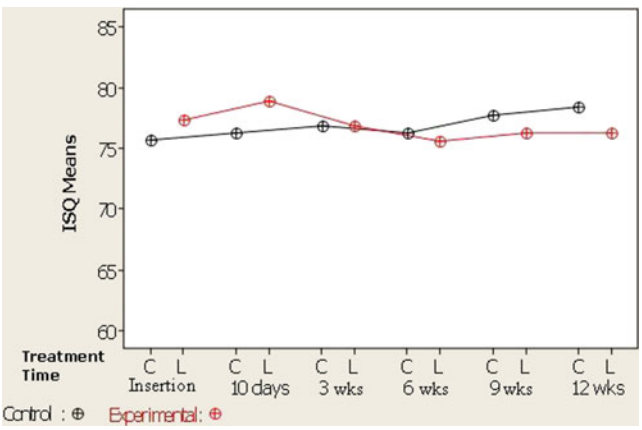

Fig. 2 ISQ means in each observation time, in the laser (L) and control (C) sides

by different authors [15–17, 33–45]. The infrared lasers are known to have a greater depth of tissue penetration in comparison to red or blue light [46], thus, the osteoblasts cells could better absorb the laser energy because of the low water absorption at that wavelength [33, 36, 45].

Kadra et al. (2004) agree that no standard protocol for laser irradiation has yet been defined with reference to implant dentistry. It has been observed that there is a very large variation in the choice of energy density and wavelengths for the use of low-level laser irradiation in bone tissue [14].

It is important to clarify that the author's intention, as postulated by WALT (the World Association for Laser Therapy), was to use a lower energy density, 9 J/cm^2 at 100 mW, aiming a biostimulation. At the display of the laser device, it was shown 9 J/cm^2, 100 mW for a spot size of 0.028 cm^2. As the power output was previously checked with the power meter, it was noticed that despite the fact the display showed 100 mW, the real power output was 86 mW. After the data of this study were obtained, it was observed that the results were different than expected, so the parameters of the laser device were checked at the Center for Lasers and Applications, Instituto de Pesquisas Energéticas e Nucleares IPEN – CNEN – USP by Prof. Dr. Zezell, and it was evidenced that the real spot size of the laser was actually 0.0028 cm^2, resulting in a calculated energy density of 92.1 J/cm^2, more then ten times higher than desired. However, the fact that the spot area was ten times smaller means that the energy per point was also smaller; actually it distributed to the tissue the same energy as if we had used a laser with a spot area of 0.028 cm^2 with a energy density of 9 J/cm^2, as previously planned.

In this study, the intraindividual longitudinal ISQ values in both groups reflected the typical course of bone healing, with a slight decrease of stability in the 6th week followed by a rise or plateau in subsequent weeks, as described by other investigators [26, 28, 47].

An increase in the ISQ values was observed in the irradiated group after 10 days of implant placements, although no statistically significant difference was found. This increase in implant stability could be attributed to an increase in cellular proliferation/differentiation and bone matrix production around the implants. The magnitude of the biomodulatory effect of laser light depends on the physiologic status of the cell at the irradiation time or stimulant effect of the laser light during the initial phase of proliferation and initial differentiation of undifferentiated cells [34].

A significant drop in stability from the 10th day to the 6th week was also observed in the irradiated group during the osseointegration period. A possible hypothesis to explain this decrease is that cells received energy in the initial stages of the repair process, accelerating their cellular

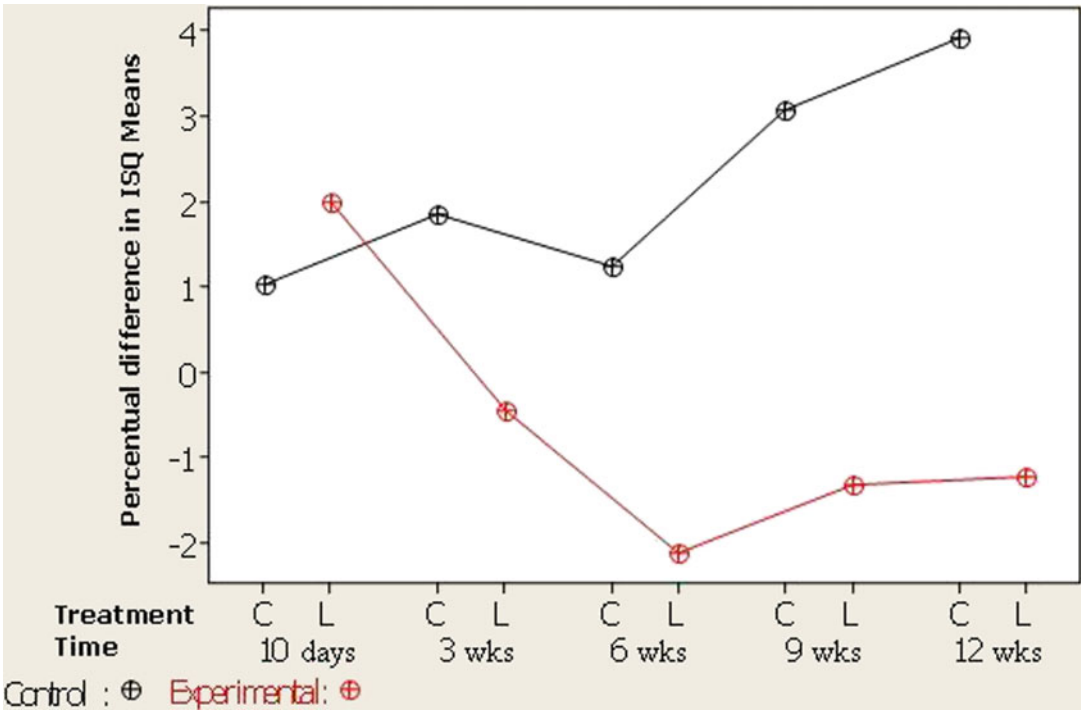

Fig. 3 Dif. % ISQ means in each observation time, in the laser (L) and control (C) sides

metabolism, and after 14 days it was suspended, probably because they were in an energy-dose-dependant situation for the subsequent metabolic processes.

According to Pinheiro and Gerbi [34], during the early stages of bone healing, the cellular component is more prominent and more prone to be affected by laser therapy. The frequency of application of laser therapy is effective when carried out during the cellular phase when the number of osteoblasts is increasing. Later, the higher number of cells results in a larger deposition of bone matrix, which later incorporates calcium hydroxylapatite, characterizing maturation of bone.

In the present study, no statistically significant differences were detected among the ISQ means in the posterior mandible between the two groups when using RFA for each of the six observations. As this study may be the first to evaluate the effect of LLLT on implant stability during osseointegration stages by means of RFA, the results cannot be directly compared to any other study.

The outcome of an implant stability analysis is highly dependent on the type of test used and the direction and type of the applied force [48]. RFA measurements essentially apply a bending load, which mimics the clinical load and direction and provides macroscopic information about the stiffness of the implant–bone interface, as bending is the most common type of loading for a dental implant [48]. The resonance frequency analysis technique has been extensively used in experimental and clinical research over the last 10 years for assessing primary stability, determining the adequate period of osseointegration before loading the implant, verifying whether sufficient stability has been attained in second-stage surgery, following-up the stability during the osseointegration process, as well as monitoring high-risk implants [21, 25–28, 30, 47, 49].

Table 3 Confidence interval of 95% for the mean difference (size effect) between control and experimental side in each time of observation

Time	Control ISQ mean	Experimental ISQ mean	Confidence interval of 95% for the mean difference	
Baseline	75.7	77.4	–5.27	1.99
10 days	76.2	78.9	–5.88	0.60
3 weeks	76.9	76.8	–2.88	6.02
6 weeks	76.3	75.5	–1.53	6.38
9 weeks	77.7	76.2	–1.73	4.87
12 weeks	78.4	76.3	–1.03	4.03

It is important to point out that there are three main factors that influence RFA: stiffness of the implant–bone interface, the total effective length above the marginal bone level, and the orientation of the RFA transducer. All of these variables were carefully considered to guarantee confident ISQ measurements.

In the present study, no effect of LLLT on implant stability was evidenced with RFA, thus it can be raised some hypotheses to explain the lack of stability improvement. One of them is that although in this study the CS and the LS belong to the same patient, it still remains uncertain if bone stimulation by laser light is a general effect or if the isolate stimulation of osteoblast is possible, although LLLT has been suggested to induce a systemic effect in distant areas such as the local treatment [37].

Another hypothesis is that the effect of the laser could have been masked by the high initial stability attained. This high initial stability can be attributed not only to the bone quality (type II bone in the posterior mandible) but also to the implant geometry. Regarding the bone quality, until the delineation of this experiment, there were no reports in the literature within the conditions of this study. The authors aimed to observe how the results would be in a normal patient, in type II bone before performing the irradiation in patients with type IV bone, in order to have an initial parameter. Further studies involving patients requiring implant treatment in areas with type IV bone quality with systemic diseases like diabetes and heavy smokers would be of great value. Regarding the implant geometry, in the study performed by Degidi et al. (2007), XiVE® implants showed high average RFA values due to their implant geometry and characteristic design to achieve a high primary stability. If the primary stability of an implant is very high, subtle changes in stiffness may not be evident [48]. The XiVE® implants were selected in order to reduce the probability of implant failure due to constant ISQ measurements in early osseointegration stages.

Although this study involved a small number of patients, special care was taken to have well-defined eligibility criteria of participants to follow a strict LLLT protocol, to use the same implants for each patient (brand, surface, length, and diameter), and to select the same edentulous region and the same study population, which enhance the design of the trial. It is important to point out that outcomes of this study are limited to the specific methodology and results may differ in different bone conditions and implants when using different LLLT protocols with other methodologies and different lengths of follow-up.

Despite the fact that lasers have demonstrated efficiency on osseous tissue healing [4, 10–14], in implantology, factors like high initial stability, implant geometry, and good bone quality, are more relevant for the quality of the implant–bone interface than any additional therapeutic effort.

Conclusions

Under the conditions of this study, using 830 nm, at 86 mW and 92.1 J/cm^2, it can be concluded that no effect of LLLT on the stability of implants was evidenced in the posterior mandible of partially edentulous patients when measured by means of resonance frequency analysis. Since high primary stability and good bone quality are of major relevancy for a rigid bone–implant interface, additional LLLT may have little impact macroscopically. Further studies with different LLLT parameters, independent group models, and under different bone conditions are necessary in order to assess other possible outcomes and to obtain a better understanding of the occurrences at the bone–implant interface.

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