Lasers Med Sci
DOI 10.1007/s10103-016-2051-3

ORIGINAL ARTICLE

Peri-implant osseointegration after low-level laser therapy: micro-computed tomography and resonance frequency analysis in an animal model

Luciano Mayer[1,2] · Fernando Vacilotto Gomes[3] · Marília Gerhardt de Oliveira[4] · João Feliz Duarte de Moraes[5] · Lennart Carlsson[6]

Received: 29 October 2015 / Accepted: 9 August 2016

Abstract The purpose of the present study is to evaluate the effects of low-level laser therapy on the osseointegration process by comparing resonance frequency analysis measurements performed at implant placement and after 30 days and micro-computed tomography images in irradiated vs nonirradiated rabbits. Fourteen male New Zealand rabbits were randomly divided into two groups of seven animals each, one control group (nonirradiated animals) and one experimental group that received low-level laser therapy (Thera Lase®, aluminum-gallium-arsenide laser diode, 10 J per spot, two spots per session, seven sessions, 830 nm, 50 mW, CW, Ø 0.0028 cm^2). The mandibular left incisor was surgically extracted in all animals, and one osseointegrated implant was placed immediately afterward (3.25ø × 11.5 mm; NanoTite, BIOMET 3i). Resonance frequency analysis was performed with the Osstell® device at implant placement and at 30 days (immediately before euthanasia). Micro-computed tomography analyses were then conducted using a high-resolution scanner (SkyScan 1172 X-ray Micro-CT) to evaluate the amount of newly formed bone around the implants. Irradiated animals showed significantly higher implant stability quotients at 30 days (64.286 ± 1.596; 95 % confidence interval (CI) 60.808–67.764) than controls (56.357 ± 1.596; 95 %CI 52.879–59.835) (P = .000). The percentage of newly formed bone around the implants was also significantly higher in irradiated animals (75.523 ± 8.510; 95 %CI 61.893–89.155) than in controls (55.012 ± 19.840; 95 %CI 41.380–68.643) (P = .027). Laser therapy, based on the irradiation protocol used in this study, was able to provide greater implant stability and increase the volume of peri-implant newly formed bone, indicating that laser irradiation effected an improvement in the osseointegration process.

Keywords Dental implants · Low-level laser therapy · Micro-computed tomography · Osseointegration

Introduction

The use of implants in the oral cavity represents a major breakthrough in the rehabilitation of partial and complete edentulism [1]. Immediate implant placement after tooth extraction not only eliminates a surgical step but also allows the use of the remaining bone after a conservative approach. Other advantages are a reduction in the time required before insertion of the definitive rehabilitation and a satisfactory aesthetic result, as desired by the patient [2]. Osseointegration of the implant is critical to achieving long-lasting implant stability. Conceptually, osseointegration is defined as the direct connection between living bone and the surface of an implant, and this process is dependent on many factors, including the morphology, composition, and characteristics of the implant surface [3].

✉ Luciano Mayer
contato@clinicamayer.com.br

1 Universidade Federal da Bahia (UFBA), Av. Araújo Pinho, 40110-912 Salvador, BA, Brazil

2 Graduate Program in Implant Therapy, Associação Gaúcha de Ortodontia (AGOR), Porto Alegre, RS, Brazil

3 Surgery and Orthopaedics Department, School of Dentistry, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil

4 Grupo Hospitalar Conceição (GHC), National Council for Scientific and Technological Development (CNPq), Porto Alegre, RS, Brazil

5 School of Math, UFRGS, Porto Alegre, RS, Brazil

6 Research and Development, Zimmer Dental Sweden, Industrivägen 4, 433 61 Gothenburg, Sweden

Published online: 17 August 2016

Low-level laser therapy (LLLT) has been used clinically in the management of several conditions based primarily on its ability to promote stimulatory effects on the biochemical and molecular processes that occur during tissue repair, leading to increased fibroblast and epithelial proliferation and increased collagen synthesis, which can accelerate the healing process. In addition, its effects are associated with restoration of nerve function after injury, normalization of hormone function, increased potential for bone repair and remodeling, reduction of inflammation and edema, regulation of the immune system, modulation and attenuation of pain, and postoperative pain management [4–10]. In dentistry, preclinical findings indicate a positive effect of LLLT on bone repair and osseointegration [11–15], and this treatment modality has become a well-accepted adjuvant tool to enhance the osseointegration process in cases of rehabilitation involving implant-supported prostheses [12–15]. Table 1 summarizes previous studies that have used LLLT (infrared), including the effect on osseointegration.

Most of the techniques that are currently available for assessing the osseointegration process, such as histology [16], histomorphometry [17], and X-ray diffraction [18], are invasive and require sample destruction and animal euthanasia, and reproducing them in humans is often difficult [19, 20]. The noninvasive assessment of bone-to-implant contact is therefore a desired approach, as the objective measurement of implant stability is very important to estimate the success of osseointegrated implants.

Resonance frequency analysis (RFA) is a noninvasive method that allows for direct measurement of the amount of bone-to-implant contact by means of objective measurement of implant stability using the Osstell® device (Osstell AB, Göteborg, Sweden) [19]. The resonance frequency of a small transducer (SmartPeg, Osstell AB) attached to the implant is measured and converted into an implant stability quotient (ISQ). Higher ISQs indicate a greater amount of bone-to-implant contact and, consequently, greater stability of the inserted implant. Acceptable stability levels range from 55 to 85 ISQ, with an average level of 70 ISQ [19, 20]. This technology provides reproducible objective measurements of lateral micro-mobility, which can be used at different stages of implant treatment [11].

Other technologies for noninvasive assessment of osseointegration have been discussed in the literature, including X-ray imaging, cone beam computed tomography, multi-slice computed tomography, and micro-computed tomography (μCT). The latter two provide a suitable option for the assessment of biological tissues [21]. Regarding the assessment of the volume of newly formed bone in contact with the implant surface, the results obtained with both histomorphometry and μCT are very detailed and of high reliability [21–23].

The present study was therefore designed to evaluate the effects of LLLT on the osseointegration process by comparing RFA measurements performed at implant placement and after 30 days and μCT images in irradiated vs nonirradiated rabbits.

Materials and methods

Ethical approval

The study was approved by the Animal Experimentation Ethics Committee of the institution (protocol no. 001/13). Animal handling and experimentation followed the Brazilian Ethical Principles of Animal Experimentation and international standards and guidelines for the care and use of laboratory animals. All efforts were made to minimize animal suffering throughout the experiments, as well as to use only the number of animals that was essential to produce reliable scientific data.

Table 1 Studies in dentistry that have evaluated the effects of low-level laser therapy (LLLT) on osseointegration using an infrared laser (800–830 nm)

Author	Year	Wavelength (nm)	Power (mW)	LLLT	Effect
Lopes et al. [32]	2005	830	10	D = 85 J/cm^2 per session; every 48 h; total of 7 sessions.	(+)
Khadra et al. [33]	2005	830	150	D = 23 J/cm^2; 9 applications of 3 J for 10 consecutive days; T = 20 s.	(+)
Kim et al. [34]	2007	808	96	PD = 830 mW/cm^2. Application immediately after surgery and for 7 consecutive days.	(+)
Lopes et al. [35]	2007	830	10	D = 86 J/cm^2 per session; every 48 h; total of 7 sessions.	(+)
Campanha et al. [15]	2010	830	10	D = 21.5 J/cm^2; T = 51 s per spot; every 48 h; total of 7 sessions.	(+)
Boldrini et al. [36]	2013	808	50	D = 11 J/cm^2; T = 1 min and 23 s; two applications immediately after site preparation.	(+)
Primo et al. [14]	2013	830	40	D = 4.8 J/cm^2; application immediately after implant placement.	(+)
Gomes et al. [24]	2015	830	100	D = 140 J/cm^2 total; 7 sessions.	(+)
Massotti et al. [27]	2015	830	100	D = 140 J/cm^2 total; 7 sessions.	(+)

D energy density, *PD* power density, *T* irradiation time, *(+)* positive effect on osseointegration

Animals

Fourteen 3-month-old male New Zealand rabbits (*Oryctolagus cuniculus*) weighing 3 to 4 kg each were used in the study. The rabbits were randomly divided into two groups of seven animals each, one experimental group and one control group. The animals were housed under standard conditions of temperature, humidity, and light intensity. They were allowed free access to solid chow (Purina, Nestlé Purina Petcare, St. Louis, MO, USA) and water throughout the experiment.

Surgical protocol

The rabbits were anesthetized with ketamine (40 mg/kg body weight; Dopalen, Vetbrands Saúde Animal, São Paulo, SP, Brazil) and xylazine (3 mg/kg body weight; Anasedan, Vetbrands Saúde Animal) injected intramuscularly. Before surgery, the area around the mandibular left incisor was cleaned with chlorhexidine gluconate 2 % (FGM Produtos Odontológicos, Joinville, SC, Brazil), and 0.5 mL of lidocaine 2 % with epinephrine (1:100,000) was infiltrated to effect local vasoconstriction. The incisor was then extracted with a no. 5 pediatric forceps (Edlo S/A, Canoas, RS, Brazil). An implant socket was prepared using sequentially sized drills under continuous saline irrigation. One osseointegrated implant (3.25ø × 11.5 mm; NanoTite, BIOMET 3i, Palm Beach Gardens, FL, USA) was then placed according to the manufacturer's instructions. Implant stability was measured, followed by placement of a cover screw and closure of the surgical site with a 4-0 monofilament nylon suture (Ethicon, Johnson & Johnson, São Paulo, SP, Brazil). With the animal under anesthesia, the area to be irradiated was shaved and the long axis of the implant was marked on the skin to guide later laser irradiation. At the end of the surgical procedure, the animals received analgesic and antibiotic therapy.

All rabbits underwent surgical extraction of the mandibular left incisor, followed by immediate placement of an osseointegrated implant. This served as the baseline clinical condition for each animal in the experiment.

LLLT irradiation protocol

Laser irradiation was performed with an aluminum-gallium-arsenide (AlGaAs) diode laser at a wavelength of 830 nm, 50-mW output power, spot area of 0.0028 cm^2, and power density (irradiance) of 17.85 W/cm^2, in continuous wave mode. Irradiation time was automatically controlled by the laser device (Thera Lase, DMC Equipamentos, São Carlos, SP, Brazil) as determined by other parameters.

The total energy per session was divided into two spots, one medial and one lateral to the long axis of the implant, as marked on the overlying skin. Animals in the experimental group received a dose of 10 J per spot, totaling 20 J per session. The laser probe was held perpendicular to the bone base, and spot irradiation was performed in contact with the skin. LLLT was performed every 48 h over a 13-day period for a total of seven treatment sessions, and the final dose was 140 J (accumulated energy of all sessions). Control animals underwent sham irradiation following the same protocol used for irradiated animals, but with the laser device left unpowered.

Implant stability measurement

RFA was used to assess implant stability based on measurements performed with the Osstell® device immediately after implant placement (time A) and at 30 days, immediately before euthanasia (time B). Four ISQ measurements were obtained on the buccal, lingual, mesial, and distal surfaces of the implant, with the tip of the handheld probe perpendicular to the transducer. The device was recalibrated after each measurement. The ISQ value for each rabbit was calculated as the average of these four measurements.

Euthanasia

On day 30 of the experiment, the rabbits were sedated and euthanized with an anesthetic overdose of propofol (1 mL/kg body weight; Lipuro 1 %, 10 mg/mL, B. Braun S.A. Laboratories, São Gonçalo, RJ, Brazil), followed by cardiac arrest induced by injection of potassium chloride 10 % (1 mL/kg body weight; Isofarma Pharmaceutical Industrial Ltda, Precabura Eusebius, CE, Brazil). The left half of the mandible was resected, and the bone portion containing the implant was fixed in 10 % neutral buffered formalin.

μCT analysis

μCT analyses were conducted using a high-resolution scanner (SkyScan 1172 X-ray Micro-CT, Bruker microCT, Kontich, Belgium). The bone portion of the mandible containing the implant and the surrounding tissues of each specimen were placed on the scanner bed for image acquisition using the control software for SkyScan 1172, version 1.6.9.3. Then, for each sample, section images were reconstructed with NRecon software (version 1.6.9.3, SkyScan). After reconstruction, the region of interest (amount of newly formed bone exactly in the central portion of the implant) was determined by drawing a cube in a virtually delimited area (1000 × 1000 × 1000 μm) between thread nos. 6 and 7 of each implant. The amount of mineralized bone tissue inside the cube was then calculated and expressed as the percentage volume of newly formed bone for each implant. Subsequently, the mean values obtained for the experimental and control groups were compared. Three-dimensional modeling and analysis of bone volume were performed with the CTAn (version 1.7.0.2, SkyScan), CTVol realistic 3D visualization (version 2.2.1, SkyScan), CTVox (version 2.4, SkyScan), and DataViewer (version 1.4.4, SkyScan) software for Windows (Fig. 1).

Statistical analysis

ISQs and percentage of newly formed bone were expressed as means and standard deviations (SDs) along with their 95 % confidence intervals (95 %CI). One-way analysis of variance (ANOVA) was used to calculate the difference between the final and initial ISQs and between μCT measurements and to analyze between-group differences in these variables, followed by Student's *t* test when the overall difference was statistically significant. The level of significance was set at 5 % ($P \leq .05$).

Results

Considering all implants tested, regardless of group, the ISQ mean value was 49.089 ± 4.400 (95 %CI 46.507–51.671) at the time of implant placement and 60.321 ± 4.460 (95 %CI 57.862–62.781) after 30 days.

The ISQ mean values obtained per group at implant placement (time A) and at 30 days (time B) are described in Table 2. Both groups showed similar ISQs at the time of implant placement, but irradiated animals had significantly higher ISQs at 30 days (64.286 ± 1.596; 95 %CI 60.808–67.764) than controls (56.357 ± 1.596; 95 %CI 52.879–59.835) ($P = .000$). Comparing the final and initial ISQs (Δ ISQ), a statistically significant difference was found between the experimental group (Δ ISQ 15.035 ± 4.369; 95 %CI 10.666–19.404) and control group (Δ ISQ 7.423 ± 7.239; 95 %CI −14.742 to 0.472) ($P = .035$) (Fig. 2).

μCT analysis showed a significantly higher percentage volume of newly formed bone in the central portion of the implant in irradiated animals (75.523 ± 8.510; 95 %CI 61.893–89.155) than in controls (55.012 ± 19.840; 95 %CI 41.380–68.643) ($P = .027$) (Table 3, Fig. 3).

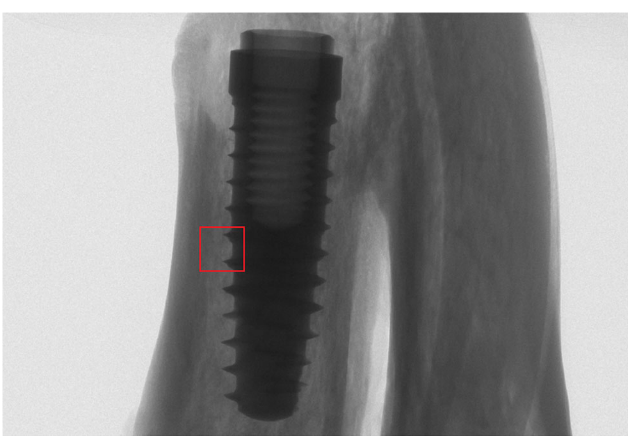

Fig. 1 Longitudinal section image of the implant inserted in the rabbit mandible obtained with the SkyScan 1172 X-ray Micro-CT scanner. The *box* indicates the area used for assessment of the percentage volume of newly formed bone in the central portion of implant (between thread nos. 6 and 7)

Table 2 ISQs (Osstell®) obtained at the time of implant placement (time A) and after 30 days (time B)

Group	Time	ISQ[a] Mean ± SD	95 %CI	*P* value
Control	A	48.929 ± 1.676	45.277–52.580	0.975
	B	56.357 ± 1.596	52.879–59.835	0.001*
Experimental	A	49.250 ± 1.676	45.598–52.902	0.975
	B	64.286 ± 1.596	60.808–67.764	0.000*

ISQ implant stability quotient, *SD* standard deviation, *CI* confidence interval

*Significantly different at $P < .05$ (one-way analysis of variance)

[a] Group means

Discussion

The present study used RFA as a noninvasive method for evaluation of the osseointegration phenomenon in a total of 14 rabbits. The main goal was to determine whether LLLT would have a beneficial effect on implant stability in early stages of osseointegration (at implant placement and at 30 days). The results showed significantly greater implant stability in irradiated than in nonirradiated animals at 30 days, as measured by RFA.

It is known that peri-implant bone repair is favored by the use of LLLT [12–14]. Laser irradiation has a positive effect particularly on the early stages of osseointegration, with a

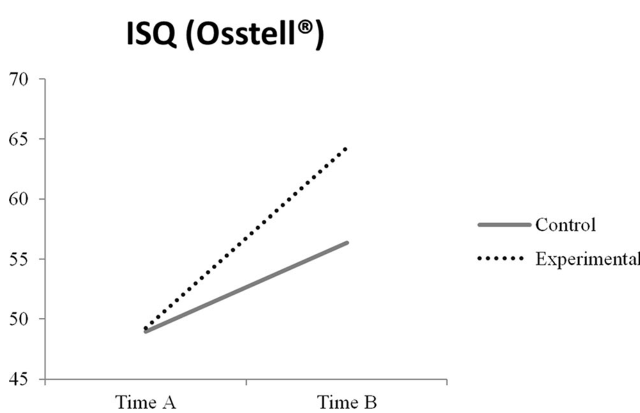

Fig. 2 Graph of mean implant stability quotients (ISQ) measured by resonance frequency analysis using the Osstell® device at the time of implant placement (time A) and after 30 days (time B)

Table 3 Percentage volume of newly formed bone in the central portion of the implant measured on μCT images

Group	% Volume of newly formed bone[a]		P value
	Mean ± SD	95 %CI	
Control	55.012 ± 19.840	41.380–68.643	0.027*
Experimental	75.523 ± 8.510	61.893–89.155	

μCT micro-computed tomography, *SD* standard deviation, *CI* confidence interval

*Significantly different at $P < .05$ (one-way analysis of variance)

[a] Group means

likewise significant increase in the removal torque values of laser-irradiated implants compared to nonirradiated controls [15]. LLLT also has a positive effect on implants with poor initial stability and low-quality bone [13]. The 20-J-per-session LLLT protocol used in the present study was able to promote an increase in the amount of newly formed bone in contact with the implant after seven sessions, which is consistent with previous observations in animals that received LLLT at the early stages of bone healing [13–15].

RFA is currently a reliable method for assessment of implant stability [24, 25]. It has also been used in research to prevent the compromise of samples during measurement of both primary and secondary implant stability, thus allowing the evaluation of the same sample content at different stages of the study [19, 20]. In the present study, in an attempt to establish a protocol for assessment of implant stability, we standardized the position of the tip of the probe, which should be held perpendicular to the transducer during all RFA measurements, and implant stability was based on the mean of four ISQ measurements (buccal, lingual, mesial, and distal surfaces), which improved the reproducibility of RFA measurements. Furthermore, an ISQ is derived from the stiffness of the bone/implant system and the calibration parameters of the transducer, and as reported in the literature, there is a correlation between low implant insertion torque values and low ISQs [25, 26].

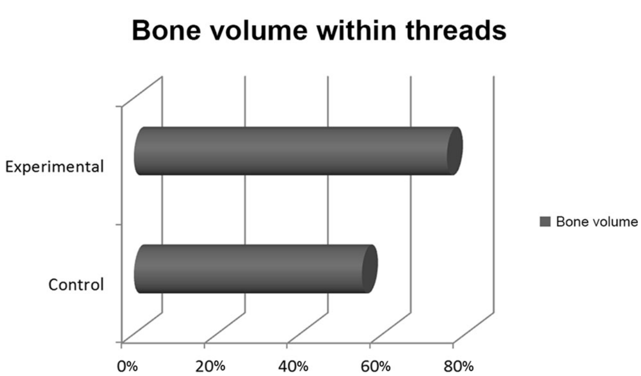

Fig. 3 Graph of the percentage volume of newly formed bone in the central portion of the implant measured on micro-computed tomography images

The gradual increase observed in ISQs over time for both irradiated and nonirradiated animals may have been caused by the process of osseointegration itself, which occurred in all animals regardless of the use of LLLT. When the ISQs obtained at implant placement and at 30 days were compared, an increase was observed in ISQs at 30 days for all animals, regardless of group. However, over time, the irradiated animals always showed ISQs that were statistically higher than those of controls.

μCT is the gold standard for assessment of bone morphology and micro-structure. This tool uses data from tomographic projections of millimetric thickness, allowing the evaluation of trabecular bone even around metallic artifacts, such as osseointegrated implants, and enables the production of high-quality three-dimensional images [24, 27–31]. In the current study, high-quality images were obtained and scattering artifacts were reduced, which allowed a proper three-dimensional assessment of the amount of newly formed bone around implants without any interference. Supporting the results obtained by RFA measurements, irradiated animals showed a greater volume of newly formed bone around the implant than controls.

In an attempt to minimize bias during μCT analysis, the region of interest selected for assessment of the amount of newly formed bone was the central portion of the implant. More cervical regions, especially in rabbits, may have recurrent or chronic inflammatory insults because of their diet and poor hygiene care. The same applies to more apical regions, most probably not only because of the bone compression that may occur when a conical implant is used, but also because of collection and approximation of bone debris on the sequence for preparation of the surgical site.

Conclusion

The present study showed significant differences in ISQs and percentage volume of newly formed bone, as measured by μCT, between irradiated and nonirradiated rabbits at different stages of the osseointegration process (at the time of implant placement and after 30 days). These findings demonstrate that LLLT at a dose of 20 J per treatment session, based on the irradiation protocol used in this study, was able to increase ISQs and the volume of peri-implant newly formed bone, reflecting greater implant stability and suggesting that the osseointegration process is favored by the use of LLLT.

Compliance with ethical standards

Financial disclosure The authors have no financial relationships relevant to this article to disclose.

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted.

References

1. Muller F (2014) Interventions for edentate elders—what is the evidence? Gerodontology 31(Suppl 1):44–51. doi:10.1111/ger.12083
2. Chen ST, Buser D (2014) Esthetic outcomes following immediate and early implant placement in the anterior maxilla—a systematic review. Int J Oral Maxillofac Implants 29 Suppl:186–215. doi:10.11607/jomi.2014suppl.g3.3
3. Carlsson L, Rostlund T, Albrektsson B, Albrektsson T, Branemark PI (1986) Osseointegration of titanium implants. Acta Orthop Scand 57:285–289
4. Coelho RC, Zerbinati LP, de Oliveira MG, Weber JB (2014) Systemic effects of LLLT on bone repair around PLLA-PGA screws in the rabbit tibia. Lasers Med Sci 29:703–708. doi:10.1007/s10103-013-1384-4
5. de Vasconcellos LM, Barbara MA, Deco CP, Junqueira JC, do Prado RF, Anbinder AL, de Vasconcellos LG, Cairo CA, Carvalho YR (2014) Healing of normal and osteopenic bone with titanium implant and low-level laser therapy (GaAlAs): a histomorphometric study in rats. Lasers Med Sci 29:575–580. doi:10.1007/s10103-013-1326-1
6. Demirkol N, Sari F, Bulbul M, Demirkol M, Simsek I, Usumez A (2015) Effectiveness of occlusal splints and low-level laser therapy on myofascial pain. Lasers Med Sci 30:1007–1012. doi:10.1007/s10103-014-1522-7
7. Fronza B, Somacal T, Mayer L, de Moraes JF, de Oliveira MG, Weber JB (2013) Assessment of the systemic effects of low-level laser therapy (LLLT) on thyroid hormone function in a rabbit model. Int J Oral Maxillofac Surg 42:26–30. doi:10.1016/j.ijom.2012.06.017
8. Gasperini G, Rodrigues de Siqueira IC, Rezende Costa L (2014) Does low-level laser therapy decrease swelling and pain resulting from orthognathic surgery? Int J Oral Maxillofac Surg 43:868–873. doi:10.1016/j.ijom.2014.02.015
9. Park JB, Ahn SJ, Kang YG, Kim EC, Heo JS, Kang KL (2015) Effects of increased low-level diode laser irradiation time on extraction socket healing in rats. Lasers Med Sci 30:719–726. doi:10.1007/s10103-013-1402-6
10. Tang E, Arany P (2013) Photobiomodulation and implants: implications for dentistry. J Periodontal Implant Sci 43:262–268. doi:10.5051/jpis.2013.43.6.262
11. Mayer L, Gomes FV, Carlsson L, Gerhardt-Oliveira M (2015) Histologic and resonance frequency analysis of peri-implant bone healing after low-level laser therapy: an in vivo study. Int J Oral Maxillofac Implants 30:1028–1035. doi:10.11607/jomi.3382
12. Khadra M, Ronold HJ, Lyngstadaas SP, Ellingsen JE, Haanaes HR (2004) Low-level laser therapy stimulates bone-implant interaction: an experimental study in rabbits. Clin Oral Implants Res 15:325–332. doi:10.1111/j.1600-0501.2004.00994.x
13. Maluf AP, Maluf RP, Brito Cda R, Franca FM, De Brito RB Jr (2010) Mechanical evaluation of the influence of low-level laser therapy in secondary stability of implants in mice shinbones. Lasers Med Sci 25:693–698. doi:10.1007/s10103-010-0778-9
14. Primo BT, da Silva RC, Grossmann E, Miguens SA Jr, Hernandez PA, Silva AN Jr (2013) Effect of surface roughness and low-level laser therapy on removal torque of implants placed in rat femurs. J Oral Implantol 39:533–538. doi:10.1563/AAID-JOI-D-10-00141
15. Campanha BP, Gallina C, Geremia T, Loro RC, Valiati R, Hubler R, de Oliveira MG (2010) Low-level laser therapy for implants without initial stability. Photomed Laser Surg 28:365–369. doi:10.1089/pho.2008.2429
16. Rea M, Lang NP, Ricci S, Mintrone F, Gonzalez Gonzalez G, Botticelli D (2015) Healing of implants installed in over- or under-prepared sites—an experimental study in dogs. Clin Oral Implants Res 26:442–446. doi:10.1111/clr.12390
17. Friedmann A, Friedmann A, Grize L, Obrecht M, Dard M (2014) Convergent methods assessing bone growth in an experimental model at dental implants in the minipig. Ann Anat 196:100–107. doi:10.1016/j.aanat.2014.02.001
18. Lee SW, Hahn BD, Kang TY, Lee MJ, Choi JY, Kim MK, Kim SG (2014) Hydroxyapatite and collagen combination-coated dental implants display better bone formation in the peri-implant area than the same combination plus bone morphogenetic protein-2-coated implants, hydroxyapatite only coated implants, and uncoated implants. J Oral Maxillofac Surg 72:53–60. doi:10.1016/j.joms.2013.08.031
19. Ostman PO, Hellman M, Wendelhag I, Sennerby L (2006) Resonance frequency analysis measurements of implants at placement surgery. Int J Prosthodont 19:77–83, discussion 84
20. Pagliani L, Sennerby L, Petersson A, Verrocchi D, Volpe S, Andersson P (2013) The relationship between resonance frequency analysis (RFA) and lateral displacement of dental implants: an in vitro study. J Oral Rehabil 40:221–227. doi:10.1111/joor.12024
21. Parsa A, Ibrahim N, Hassan B, van der Stelt P, Wismeijer D (2015) Bone quality evaluation at dental implant site using multislice CT, micro-CT, and cone beam CT. Clin Oral Implants Res 26:e1–7. doi:10.1111/clr.12315
22. Anil S, Cuijpers VM, Preethanath RS, Aldosari AA, Jansen JA (2013) Osseointegration of oral implants after delayed placement in rabbits: a microcomputed tomography and histomorphometric study. Int J Oral Maxillofac Implants 28:1506–1511. doi:10.11607/jomi.3133
23. Finelle G, Papadimitriou DE, Souza AB, Katebi N, Gallucci GO, Araujo MG (2015) Peri-implant soft tissue and marginal bone adaptation on implant with non-matching healing abutments: micro-CT analysis. Clin Oral Implants Res 26:e42–46. doi:10.1111/clr.12328
24. Gomes FV, Mayer L, Massotti FP, Baraldi CE, Ponzoni D, Webber JB, de Oliveira MG (2015) Low-level laser therapy improves peri-implant bone formation: resonance frequency, electron microscopy, and stereology findings in a rabbit model. Int J Oral Maxillofac Surg 44:245–251. doi:10.1016/j.ijom.2014.09.010
25. Ohta K, Takechi M, Minami M, Shigeishi H, Hiraoka M, Nishimura M, Kamata N (2010) Influence of factors related to implant stability detected by wireless resonance frequency analysis device. J Oral Rehabil 37:131–137. doi:10.1111/j.1365-2842.2009.02032.x
26. Eslamian L, Borzabadi-Farahani A, Hassanzadeh-Azhiri A, Badiee MR, Fekrazad R (2014) The effect of 810-nm low-level laser therapy on pain caused by orthodontic elastomeric separators. Lasers Med Sci 29:559–564. doi:10.1007/s10103-012-1258-1
27. Massotti FP, Gomes FV, Mayer L, de Oliveira MG, Baraldi CE, Ponzoni D, Puricelli E (2015) Histomorphometric assessment of the influence of low-level laser therapy on peri-implant tissue healing

in the rabbit mandible. Photomed Laser Surg 33:123–128. doi:10.1089/pho.2014.3792

28. Mangione F, Meleo D, Talocco M, Pecci R, Pacifici L, Bedini R (2013) Comparative evaluation of the accuracy of linear measurements between cone beam computed tomography and 3D microtomography. Ann Ist Super Sanita 49:261–265. doi:10.4415/ANN_13_03_05
29. Pyo SW, Kim YM, Kim CS, Lee IS, Park JU (2014) Bone formation on biomimetic calcium phosphate-coated and zoledronate-immobilized titanium implants in osteoporotic rat tibiae. Int J Oral Maxillofac Implants 29:478–484. doi:10.11607/jomi.3423
30. Bouxsein ML, Boyd SK, Christiansen BA, Guldberg RE, Jepsen KJ, Müller R (2010) Guidelines for assessment of bone microstructure in rodents using micro-computed tomography. J Bone Miner Res 25:1468–1486. doi:10.1002/jbmr.141
31. Le BT, Borzabadi-Farahani A (2014) Simultaneous implant placement and bone grafting with particulate mineralized allograft in sites with buccal wall defects, a three-year follow-up and review of literature. J Craniomaxillofac Surg 42:552–559. doi:10.1016/j.jcms.2013.07.026
32. Lopes CB, Pinheiro AL, Sathaiah S, Duarte J, Cristinamartins M (2005) Infrared laser light reduces loading time of dental implants: a Raman spectroscopic study. Photomed Laser Surg 23:27–31
33. Khadra M (2005) The effect of low level laser irradiation on implant-tissue interaction. In vivo and in vitro studies. Swed Dent J Suppl 172:1–63
34. Kim YD, Kim SS, Hwang DS, Kim SG, Kwon YH, Shin SH, Kim UK, Kim JR, Chung IK (2007) Effect of low-level laser treatment after installation of dental titanium implant-immunohistochemical study of RANKL, RANK, OPG: an experimental study in rats. Lasers Surg Med 39:441–450
35. Lopes CB, Pinheiro AL, Sathaiah S, Da Silva NS, Salgado MA (2007) Infrared laser photobiomodulation (lambda 830 nm) on bone tissue around dental implants: a Raman spectroscopy and scanning electronic microscopy study in rabbits. Photomed Laser Surg 25:96–101
36. Boldrini C, de Almeida JM, Fernandes LA, Ribeiro FS, Garcia VG, Theodoro LH, Pontes AE (2013) Biomechanical effect of one session of low-level laser on the bone-titanium implant interface. Lasers Med Sci 28:349–352. doi:10.1007/s10103-012-1167-3