The Adjunctive Use of the Er:YAG 2940 nm and Diode 980 nm Lasers in Guided Bone Regeneration: A Case Report

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Abstract

Background: The adjunctive use of laser devices in dentistry is considered as a great advantage to obtain optimal results including in guided bone regeneration (GBR) procedures. The aim of this case report is to present the benefits in using Er:YAG laser and a 980 nm Diode laser in management of osseous defect by GBR.

Methods: The Er:YAG is used to prepare a sinus lift by crestal approach and to uncover the implants for impression and final restoration, a flattop handpiece connected to a 980 nm diode laser was used for PBMT for bone regeneration.

Result: The use of laser devices had improved the regeneration process and shortened the time for treatment.

Conclusion: Er:YAG laser and PBMT are beneficial during the bone regeneration process.

Keywords: Bone Regeneration; Dentistry; Diode; Erbium YAG; Laser; Implant Restoration; Sinus Lift

Abbreviations

GBR: Guided Bone Regeneration; PBM: Photobiomodulation; ER:YAG: Erbium-YAG; MesH, AAP, CBCT

Introduction

Guided bone regeneration (GBR) has been defined as the use of barrier membranes, either resorbable or not, to exclude certain cell types such as rapidly proliferating epithelium and connective tissue, thus promoting the growth of slower-growing cells capable of forming bone. GBR is often combined with bone grafting procedures [1]. This technique has been shown to produce excellent

and reproducible results with high long-term success rates, based on high evidence level publications [2]. Clinicians should always take into consideration the key factors for success in GBR, including patient selection, tissue defect analysis, blood supply, bone preparation, flap passivation, membrane fixation, primary closure and healing complications; however, the time needed to achieve adequate osseous regeneration must be greater than 6 months.

Laser devices, thanks to their biological and physical effects, can be considered the best alternative to achieve an outcome with a minimum time required, with respect to the key factors cited above. The use of laser technology has been widely cited in the

literature to have beneficial effect on both hard and soft tissue, thanks to their photophysical and photobiological effects [3]. The Erbium-YAG (2940 nm) laser is considered one of the best instruments in oral surgery and presents many advantages compared to other mechanical alternatives, offering more blood supply, better bone surface to accept the graft material, suppression of the thermal stress and mechanical vibration [4-6]. Other wavelengths can play an important role in the management of biological processes; these wavelengths are included within the so-called optical window (600 - 1200 nm) [7] and subject to sub-ablative applied dose, offer the possibility to achieve a biological response inside the tissue termed photobiomodulation (PBM). Photobiomodulation has been defined as the manipulation of the cellular behavior using low intensity light sources. Photobiomodulation therapy replaces low level laser therapy and was added to the medical subject headings (MeSH) database in 2015. It is considered as an evidence-based therapy and effective in bone repair processes [8].

Aim of the Study

The aim of this case report is to demonstrate the efficacy of the Er:YAG laser, together with photobiomodulation in bone repair and regeneration of a wide osseous defect. This is the first time, in our opinion, that this procedure, combining a sinus lifting by crestal approach and two laser wavelengths, has been performed.

Case Presentation

A 57-year-old male patient, nonsmoker, was referred in 2018 to replace his two upper right molars (tooth #16 and #17), extracted a year ago due to a periodontal abscess and tooth mobility. Appropriate periodontal maintenance had been provided during the intervening period prior to referral. The patient was in general good health and without any personal or family medical history. The patient had attained meticulous oral hygiene, and there was absence of bleeding on probing and mobility of residual teeth; with thick (> 1 mm) gingival phenotype according to the new classification of the American Academy of Periodontology (AAP) [9]. Comprehensive clinical and radiographic evaluations were performed (Figure 1-3). The edentulous ridge presented a class C medium defect according to the classification of Wang and Al-Shammari [10]. Many alternatives were proposed to the patient to replace his missing teeth, including a partial removable denture and guided bone tissue regeneration procedure followed by an implant-supported screw-retained fixed bridge. The latter option was chosen by the

patient. Treatment details were explained to the patient and an informed consent was signed before the beginning of treatment.

Figure 1: Panoramic view before treatment.

Figure 2: CBCT before treatment (axial view).

Figure 3: Pre-treatment appearance (teeth 17 and 16 missing).

Case management

Treatment for this patient to restore his missing teeth in accordance with his preferences would involve several stages and this will include:

- Sinus lift surgery with graft bone regeneration (GBR), using a crestal approach
- Implant placement
- Second stage surgery to uncover the implants
- Restoration: Screw-retained bridge on implants to replace the 2 missing teeth.

It was considered beneficial to use the laser devices during the first three stages to manipulate both hard and soft tissue. The erbium -YAG (2940 nm) laser was used to prepare the crestal window, to prepare the bone to receive the graft material and to uncover the implants during the third step prior to the impression. A flat-top hand-piece connected to a 980 nm diode laser was used for photo-biomodulation after GBR, to promote osseous tissue regeneration and after implant placement in order to promote osseointegration.

The operatory room was decontaminated 30 minutes before the surgery, by NOCOS Spray. Laser warning signs were placed and the operating room was secured. The two laser devices were set up and test-fire carried out prior to surgery. Supplies were dispensed and sterile instruments arranged (Figure 4). The patient was treated in an ante-room to take blood samples via catheter for Injectable Platelet Rich Fibrin (iprf), using a centrifuge separation (Figure 5). Prior to laser use, eye protection goggles were placed to the patient first, then to assistants and operator. In this particular case, two sets of goggles were used, the first to protect from the 2940 nm wavelength and the second to protect from 980 nm wavelength (Figure 6).

The intra-oral surgical site was disinfected using a polyvidone-iodine solution 10% and an infiltration of local anaesthetic was administered (Articaine, 1/200000 adrenaline), on the buccal and palatal aspects. An offset crestal incision on the palatal side was performed from the distal side of tooth 15 to the maxillary tuberosity, followed by a vertical releasing incision, placed at the mesial line angle of tooth 15. The choice of technique was made in accordance with the dental cone-beam computed tomography (CBCT) examination, where the position of the alveolar antral artery was

Figure 4: Instrument arrangements before the surgery: (a) warning signs; (b) instruments arranged; (c) laser tested and ready to use.

Figure 5: Centrifuge separation for injectable platelet rich fibrin.

detected near to the site of the osteotomy in the case of lateral approach. After full-thickness flap reflection, the erbium laser was used to prepare the sinus window by crestal approach (Figure 7).

Figure 6: Eye protection: (a) Protection for Er:YAG laser; (b) Protection for diode laser.

Figure 7: First steps of the surgery: (a) full thickness flap; (b) preparation of the crestal window by the mean of Er:YAG laser; (c) crestal window prepared.

The site preparation was performed using the laser parameters in table 1, using a continuous movement, at a distance between 0.5 mm and 1 mm from the tissue and a speed of 1 mm/second. At the end of the osteotomy, a Valsalva testing was performed to exclude the possibility of communication with the sinus cavity. During this part of the procedure, a second assistant prepared the graft material using a mix of the iprf and 3g of collagenated corticocancellous equine bone particles (granulometry 250 - 1000 mm, GEN-OS®, Osteobiol-Tecnoss, Turin, Italy) to provide a sticky bone aspect at the end.

Energy per Pulse: 180 mj	Total Energy: 3672j
Average Power: 3.6w	Peak Power: 1200 w
Frequency: 20 Hz	Water: 55 ml/min
Pulse Duration: 150 µsec	Air: 90%
Tip to Tissue: 0.5 to 1 mm	Time taken: 17 min
Tip Diameter: 800 µm	Energy density with movement: 288 j/cm ²
Spot diameter at tissue: 0.0123 cm ²	Emission Mode: FRP

Table 1: Laser parameter of the Er:YAG 2940 nm for bone sinus window.

The bone grafting material obtained was placed within the defect caused by elevation of the sinus floor membrane and a resorbable collagen membrane (Evolution® Osteobiol-Tecnoss, Turin, Italy) was placed over the graft material and secured with two pins (Figure 8).

The flap was repositioned and passively secured using sutures. Sub-ablative laser irradiation to induce PBM was applied at 3 sites: buccal, palatal and crestally, using a flattop handpiece (AB2799; Doctor Smile) with parameters listed at table 2. During the procedure, the handpiece was kept still and the fluence delivered was 45 j/cm² per session, during 2 weeks with 48 hours interval (6 sessions) (Figure 9). A prescription of Amoxicillin+ clavulanic acid 2 gr per day, for a week was given to the patient, together with 1000mg of paracetamol every 6 hours if needed for pain management.

After 2 months, a CBCT scan was performed to evaluate bone regeneration, and then the decision was taken to perform the second step of implant placement (Figure 10). Before the second surgery,

Figure 8: This is a figure showing preparation of graft material and GBR: (a) aspiration of iprf; (b) sticky bone prepared; (c) Bone graft in place; (d) pins to secure the graft.

Power: 0.3w	
Emission mode: CW	
Hand-piece: Flattop (flat profile)	Length of treatment per session: 150 sec
Tip area: 1 cm ²	
Fluence per session: 45 j/cm ²	

Table 2: Laser parameter of 980 nm diode for PBM.

Figure 9: Preparation of graft material and GBR: (a) aspiration of iprf; (b) sticky bone prepared; (c) Bone graft in place; pins to secure the graft.

it was decided with the patient's acceptance, to take a small piece of the bone from the implant site preparation for histological evaluation. A trephine of 3mm of diameter was used, prior to implant placement, to take the bone from the implant bed site; the bone was placed into a receptacle containing formaldehyde 40%. The implant beds were then prepared according to the manufacturer protocol and 2 implants 5*10 mm ETK Naturactis implants (Etk, Lyra company, France) were placed with a final torque of 35 N/cm to insure primary stability. At the end of the surgery, a photobio-modulation was performed using the same parameters cited above (Figure 11).

Figure 10: CBCT radiograph after 2 months.

Figure 11: Second steps of the treatment: (a) flap release; (b) good bone regeneration; (c) trephine to collect bone; (d) bone in a receptacle; (e) implant placement; (f) PBMT.

The third step of implant uncovering was done 3 months later; a 2940 nm Er-YAG laser was used to uncover the implants without anesthesia, with the parameters cited in table 3. The impression was taken the same day and the final restoration placed one week after (Figure 12).

Energy per Pulse: 143 mj	Total Energy: 901j
Average Power: 5w	Peak Power: 953 w
Frequency: 35 Hz	Water: 10 ml/min
Pulse Duration: 150 µsec	Air: 90%
Tip to Tissue: 0.5 to 1 mm	Time taken: 3 min
Tip Diameter: 600 µm	Energy density with movement: 474 j/cm ²
Spot diameter at tissue: 0.0087 cm ²	Emission Mode: FRP

Table 3: Laser parameter of the Er:YAG 2940nm for implant uncovering.

Figure 12: The final restoration: (a) emergence profile after 1 week of the Er:YAG preparation; (b) Screw-retained bridge; (c) palatal side; (d) buccal side.

A radiographic assessment was done at the end of the treatment to evaluate the good adaptation of the restoration with both soft and hard tissue (Figure 13). The long-term prognosis of the treat-

ment provided should be considered as good. The patient continues to maintain good oral hygiene and attends for assessment as required.

Figure 13: Post-treatment panoramic X ray (5 months follow up).

Results and Discussion

The aim of this case report is to assess the efficacy of the use of laser devices in combination with guided bone regeneration, to treat a bone defect and to make the procedure easy, comfortable and with less time required. In this case, two wavelengths were chosen to treat the patient - a 2940 nm Er:YAG laser and a 980 nm diode laser, and a special hand-piece for photobiomodulation. All the surgical procedures performed for this patient were in complete accordance with the concept of minimum invasive dentistry, which lead to no particular post-op complications and less time needed to complete the case. In this case report, the histological analysis had shown a good regeneration of bone defect and the substitution of the graft material allowing the implant placement with good primary stability and high torque of insertion (35 N/cm) in only 2 months (Figure 14).

The bone augmentation procedure chosen in this particular case was a sinus lift by crestal approach and delayed implant placement. The choice has been indicated after the Xray examination. In fact, the CBCT showed a ridge height less than 2 mm that contraindicated the simultaneous implant placement together with proximity of the alveolar antral artery which could relatively contraindicated the lateral window approach [11].

Figure 14: Histological analysis (HE x100 and HE x 200): (a) mature bone; (b) osteoblast; (c) osteocytes; (d) Blood vessels; (e) fibroblasts.

Sinus augmentation has been shown to be an effective surgical technique to augment a vertical ridge defects. Many techniques have been described in the literature a clinician can choose from. However, the lateral and the crestal osteotomies approaches technique have been the most discussed [12]. In this case, the antrostomy performed was by crestal approach with the technique described by Winter, *et al* [13]. Carlo, *et al* [14] reported in a case series report that crestal window sinus lift is predictable procedure for lifting maxillary sinus floor less than 2 mm with minimal pre and postsurgical complications. Isidori, *et al* [15] in a prospective study reported that during the surgeries and the observation periods, no complications were recorded and no infection or inflammation was observed and concluded that the sinus lift by crestal approach can be a good alternative to the sinus lift procedure with a lateral window as it reduces the duration of surgery and discomfort. Pal, *et al* [16] compared the technique of antrostomy lateral and crestal approaches and they found that both techniques did not affect the implant success rate, although the crestal approach appeared more comfortable for the patient while in the lateral approach the gain in bone height was greater. Different devices have been described to perform the antrostomies such as mechanical drill or piezotome [17]. The Er:YAG laser can be considered as a new alternative to open a sinus window.

The Er:YAG laser has shown to be effective in soft and hard tissue cutting, due to the great absorption of this particular wavelength in molecular water and hydroxyl ions of hydroxyapatite,

resulting in effective thermomechanical tissue ablation. Moreover, the short pulse duration compared to the thermal relaxation time, together with the water irrigation will avoid excessive heating of the bone and the surrounding tissue during irradiation [18,19]. Also, compared to conventional techniques, the Er:YAG laser provides a noncontact and no or low vibration intervention which will lead to very precise cutting and rapid osseous healing. Wang, *et al* [20] reported in an *in-vivo* study in rabbits where they created perforations in the jaws with an Er,Cr:YSGG (2780 nm) laser that this device facilitates precise surgical ablation with minimal thermal damage to adjacent tissues and the healing process was favorable.

Dragana, *et al* [21], in a comparative *in-vitro* study, compared osteotomies performed with low speed pilot drill and an Er:YAG laser and he reported that the laser ablation did not cause any chemical or crystallographic changes of the bone tissue compared to the drill, and that the Er:YAG laser created well-defined edges of the preparations without smear layer. De Mello, *et al* [22] compared the bone repair process after osteotomies performed either with the Er:YAG laser or with the low-speed bur drilling on rats, the concluded that the Er:YAG laser successfully promoted the ablation of the bone tissue without mechanical vibration or pressure and it could be an alternative for replacing high and low-speed bur with precise, fast and selective cutting. Baek, *et al* [23], investigated the bleeding rate and the healing process after osteotomies and incision on animal models made either with the Er:YAG laser and a piezotome device and they concluded that the piezo osteotomies results on flattened and closed surface with cracks and scratches caused by the tip of the instrument, while Er:YAG osteotomies showed open surface and intact tissue structure leading to greater bleeding and consequently results in rapid bone healing. Gabrić, *et al* [24] conducted an *in-vivo* animal study where they compared the healing process after osteotomies performed by piezosurgery device, Er:YAG laser in contact mode and Er:YAG in non-contact mode and they reported that osteotomies done with Er:YAG laser in non-contact mode healed faster. Kesler, *et al* [25], demonstrated that the secretion of the platelet derived growth factor (PDGF) remains continuous after osteotomies done with Er:YAG laser, compared to the mechanical drill, and they reported that the Er:YAG laser may enhance the bone regeneration by increasing the amount of platelet derived growth factor present in the stem cells resulting in magnification of the natural bone regeneration pathway on to a

mature graft. Few reports describe the use of Er:YAG laser device for bone window osteotomy. Sohn, *et al.* [26] reported, in a case series where they used an Er:Cr:YSGG laser to perform lateral sinus window, that the cuts were precise, straight and clean with minimal damage to the surrounding tissues and that the infection and post-operative pain were both reduced. However, the membrane perforation occurs in 10 - 44% of cases, but not related to laser ablation. Matys, *et al.* [27] assessed the time of preparation, bone temperature and the Schneiderian membrane perforation rate during maxillary sinus floor elevation either by the use of diamond bur or an Er:YAG laser in the pig. They reported a significantly lower rate of the Schneiderian membrane perforation in the laser group compared with the bur ($p < 0.05$). The significantly higher increase in temperature was found in the diamond bur group ($p < 0.05$), however the average time necessary for the laser bony window osteotomy was greater than the ones performed with the diamond bur.

The other laser device used in this case is a 980nm diode laser. This wavelength is well absorbed by melanin and hemoglobin and some proteins but poorly absorbed by water; resulting in a specific physical characteristic which is tissue penetration. With a low dose of energy applied, the photonic energy delivered by the diode laser will be scattered within the tissue and will be absorbed by specific chromophores, to give rise to a biological effect which is photobiomodulation.

In this case photobiomodulation was performed to take advantage of its main effects such as induced analgesic effect, suppression of inflammatory response and promotion of healing mechanisms. After 48 hours from the first step of the surgery, the patient presented with a small swelling and affirmed that pain sensation was acceptable without the need for paracetamol (Figure 15).

DelVecchio, *et al.* [28], reported in a double-blinded clinical controlled study a statistical significance between the treated group with PBM and the placebo group and confirmed that PBM is effective in reducing pain related to temporo-mandibular joint disorders. Tenis, *et al.* [29] conducted a randomized double-blind controlled clinical study to evaluate the effectiveness of the PBM in pain management, facial edema, trismus and quality of life after extraction of retained lower third molars and reported that the PBM was effective in pain relief and the control of postoperative

Figure 15: Patient after 48h: (a) good healing of the surgical site; (b) small swelling.

sequelae. Chow, *et al.* [30] performed a review where he provides strong evidence of the inhibition of neural function as a mechanism for the clinical application of PBM in pain management.

In this case report, the histological and the radiographic assessments showed that the bone healing and regeneration was greater and faster than the results obtained with other conventional methods, where the complete bone regeneration was seen after at least 6 months.

Thus, the photobiomodulation had a substantial role to accelerate bone formation. Several studies have evaluated the advantage of the use of PBM therapy to promote bone regeneration. Akyol, *et al.* [31], conducted an *in-vivo* study on animal models, where they perforated the femur of Wistar rats and they induced diabetes in the experimental group, prior to PBM. The results were compared to a rat control group of non-diabetics. They concluded that at 20 days the healing process was better in the diabetic group than the non-diabetics group. Pretel, *et al.* [32], conducted an *in-vivo* comparative study on animals where they assessed the bone remodeling in two groups of rats presenting with bone defects; the first group was designed as a control group while the second was treated with PBM. They concluded with the help of histological analysis that the bone formation in the laser group was higher than the control group with a statistical significance ($p < 0.05$) on the first phase of inflammatory response. Sella, *et al.* [33], reported that PBM is effective in enhancing bone healing in a rat nonunion

femoral fracture model *in-vivo*, and the photobiomodulation has an effect on all phases of this repair process by increasing the expression of bone formation proteins *in-vivo* and by shortening all phases of bone remodeling. Gerbi, *et al.* [34] assessed the effect of PBM on the repair of defects created in the femurs of Wistar rats treated with bone morphogenic proteins (BMPs) and organic bovine graft. The authors noticed increased deposition of collagen fibers as well as an increased amount of well-organized bone trabeculae at the end of the experimental period of 30 days in the irradiated areas and they concluded that PBM with BMPs and organic bone grafts increased osseointegration of biomaterials. The handpiece used in this case for photobiomodulation is "the Genoa flattop handpiece". The main advantage of this handpiece is the flat profile compared with the other handpieces which presented a Gaussian profile and a loss of fluence from the center to the periphery, as well as beam divergence and fluence loss when the distance between the tissue and the handpiece is increased. The flattop handpiece offers the possibility to have the same fluence at every point of the surface of the irradiated zone even if the distance increased [35]. Ferrando, *et al.* [36], reported in an *in-vitro* comparison between a Gaussian handpiece and a flattop handpiece that the use of this type of handpiece was more effective and reproducible in affecting the stored Ca^{2+} by increasing the intracellular concentrations of this ions. Hanna, *et al.* [37], performed a comparative study between the flattop handpiece and a standard Gaussian handpiece to accelerate bone regeneration and reported that the flattop handpiece has better photobiomodulatory efficacy on pre-osteoblastic cell differentiation, due to its homogeneous energy distribution at each point of its cross-section.

Despite the beneficial effect of PBM that has been shown in this case and in other studies, the mechanism of PBM during bone remodeling and regeneration remains unclear; some studies reported that the improvement of the vascularization after application of PBM therapy can be one the possible mechanism that can explain the efficacy of that treatment [38]. Renata, *et al.* [39] studied the activity of bone cells after PBM, close to the site of injury and they reported that PBM therapy increases the activity of osteoblasts and osteoclasts around the site of the repair without alteration of bone architecture during the inflammatory period. Another possible mechanism is that PBM can biostimulate the proliferation and differentiation of mesenchymal cells into osteoblasts and the induction of ossification [40]. Arany, *et al.* [41] reported that non-

ionizing low-power laser treatment can be used as a minimally invasive tool to activate an endogenous latent growth factor complex, transforming growth factor- $\beta 1$ (TGF- $\beta 1$), that subsequently differentiates host stem cells to promote tissue regeneration.

It is clear that the laser devices and the PBM therapy specifically, have a positive impact by accelerating the bone regeneration process; however, the mechanism of action of the lasers on a cellular level remain unclear and needs to be further investigated.

Conclusion

The results obtained in this clinical case affirmed the advantage in use of laser devices and PBM in the management of a large bone defect by promotion of tissue repair and acceleration of bone regeneration. Within the limitation of this case report, more investigation must be performed to prove the efficacy of the PBM in bone regeneration and to assess the possible mechanism of this therapy at cellular level.

Conflicts of Interest

The authors declare no conflict of interest.

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Volume 5 Issue 11 November 2021

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