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Effect of the laser beam on implant site preparation: a preliminary pilot study

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Abstract

The aim of this preliminary study is to histologically evaluate the effects of erbium-doped yttrium aluminum garnet (Er:YAG) laser on soft and hard tissues during implant bed preparation, in comparison with bur and cutter in order to observe the following aspects: (*i*) the shape of the cavity, (*ii*) the presence of debris, and (*iii*) structural modification of the cell architecture. Bone temperature changes during the preparation of the implant bed were also measured in order to evaluate thermal damage on soft and hard tissues. Er:YAG laser, Fotona X-Runner scanner and circular cutter of 5 mm diameter were compared using an *in vitro* model. Implant bed preparations were performed in bovine rib bone (hard tissue) and tongue muscle (soft tissue) tissues. Results of the study show that in all bur samples were present more debris and more blood cells than in laser samples, which, according to the rules of healing processes, can be a negative factor for the osseointegration process. Regarding the thermal effects on soft tissue, they were present when using MAX mode, but absent when using quantum square pulse (QSP) mode. A preliminary conclusion emphasizes the use of laser to prepare the implant site without debris formation. Nowadays, is not still present a laser device that can overtake the technical limitations of the laser scanner (*i.e.*, deepness control and scanner movement during the preparation of the holes, etc.).

Keywords: Er:YAG laser, implant bed preparation, histological examination, thermal effect.

Introduction

The introduction of endosseous implants in dentistry was the beginning of a new era in dental medicine and the following years have brought many improvements to the implant designs and their insertion techniques. Nowadays, dental implants represent a treatment method, which is well integrated in the daily practice of many dentists. In particular, the use of endosseous titanium implants for replacing missing teeth for both completely and partially edentulous patients has been proven to be a successful treatment modality. This phenomenon, known as osseointegration, has been characterized as a direct structural and functional connection between organized, living bone and the surface of a load-bearing implant. Therefore, it is compulsory, for obtaining a good osseo-integration, to have a direct bone-to-implant contact (BIC), without the interposition of any other types of tissues [1–3].

There are several studies regarding different methods of enhancing bone formation around implants, including: hydroxyapatite pre-coating, impregnation of porous material with calcium phosphate and carbon coating [4–7].

However, many studies are still conducted in order to establish the optimal protocol for creating a strong BIC. We have to take into consideration, for instance, heat formation during conventional drilling procedures, knowing that the temperature of around 47°C (*i.e.*, 10°C above the body temperature) was reported to cause osteocyte damage, thus affecting negatively the osseointegration of endosseous implants. The necrotic cortical bone continues to support the implant mechanically in the initial phase of healing until it is substituted by new vital bone which will take care of providing the support necessary for the stability of the implant. This event leads to the loss of the primary stability, which lasts until bone integration takes place with the appearance of a new stability called "secondary stability". During the healing process, primary stability will diminish while secondary stability will take place only after several weeks. In order to minimize the risk of temperature increase in the adjacent alveolar bone, an intermittent drilling technique under adequate irrigation with sterile saline solution has been recommended. However, several *in vitro* studies have also shown that temperatures may increase when drills are used multiple times [8–11].

Recently, the use of laser radiation has shown to be an alternative or adjunctive treatment for bone tissue ablation due to the vaporization of the tissues and absence of the smear layer [12–15].

Among many alternatives regarding wavelengths, it has been shown that erbium-doped yttrium aluminum garnet (Er:YAG) laser with a wavelength of 2940 nm, in the near infrared spectrum, can provide an effective ablation of the bone, without producing major thermal side effects to adjacent tissues, since this wavelength is absorbed by endogenous and exogenous water [16, 17].

For these reason, this laser may also be a promising tool for bone ablation during implant bed preparation and osseointegration of titanium implants. However, there is not any clear evidence on laser treatment of tissues for implant site preparation, both in the literature and in the daily clinical practice, regarding the effects and the efficiency on soft and hard tissues.

Moreover, another important aspect is the implant site preparation is the geometric repeatability of the bone site.

Respect for the surgical sequences for implant site preparation, with calibration cutters growing up to the desired diameter, allow us to achieve optimum positioning of the fixture, allowing an adequate BIC value, thus obtaining a high success predictability as far as concerns the osseointegration process.

Up to now, proper laser devices useful to create a repeatable bone site is missing and so far very few improvements in the developing of cutting instruments for implant surfaces are made.

Aim

The aim of this preliminary study is to evaluate and compare the use of Er:YAG laser or conventional methods (bur and cutter) on hard and soft tissues using an *in vitro* model. From a histological point of view, we compare bur and cutter implant site in order to evaluate: the shape of the cavity, the presence of debris, structural modification of cell architecture, the effect of different laser mode and the evaluation of thermal damage on soft and hard tissues.

Materials and Methods

Bovine tongue was used as soft tissue due to the presence of superficial dorsal non-keratinized and ventral mucous non-keratinized tissues, which are histologically similar to non-keratinized gingival tissue. Bovine rib was used as hard tissue since it is very similar to human jaw regarding the bone density and the cortical/marrow ratio. Er:YAG laser, Fotona X-Runner, and circular cutter were used. Holes preparation on the soft tissue was carried out using the Er:YAG (2940 LightWalker AT, Fotona Slovenia – Figure 1) laser with a 5 mm diameter scanner (X-Runner, Fotona, Slovenia) in MAX mode and quantum square pulse (QSP) mode in comparison to a circular scalpel of 5 mm in diameter. The Er:YAG laser was used in the same way to drill holes on hard tissue compared to the traditional surgical sequence with increasing calibration cutters up to a diameter of 5 mm (Figure 2). Both in hard and soft tissues, holes were prepared using MAX mode (six samples), QSP mode (six samples) and punch cutter as control for soft tissue (one sample) and BUR (1200 rpm, 40 N torque) as control for hard tissue (six samples).

Figure 1 – ***Scanner handpiece (A) and settings for laser preparations in soft tissue (B and C).***

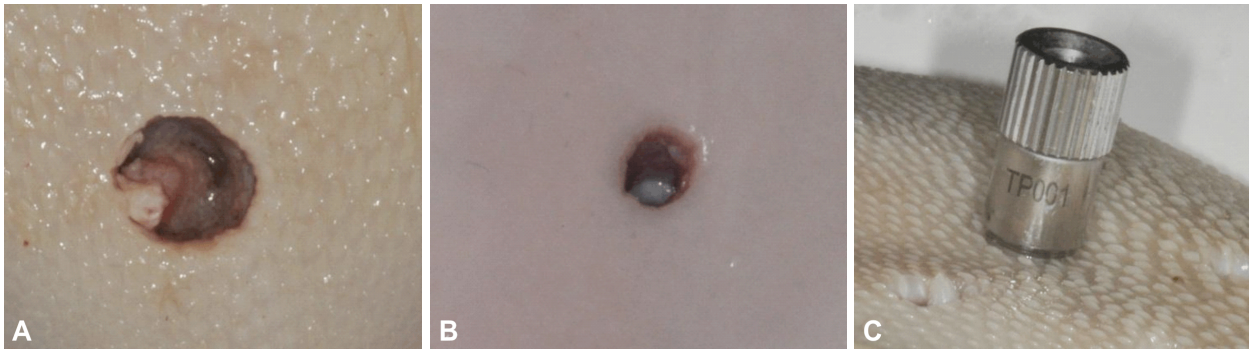

Figure 2 – ***Different approach to create a soft tissue model of 5 mm in diameter of the implant site with Max mode (A), QSP mode (B), circular cutter (C). QSP: Quantum square pulse.***

Three samples of each group (soft tissue and hard tissue) were sealed with silicone (Light Body – Aquasil Ultra, Dentsply) in order to maintain the shape during the following stages and to avoid contamination of the cavity. Bone samples were collected in duplicate. The bone samples were decalcified [2–4% hydrochloric acid, 4–6% ethylenediaminetetraacetic acid (EDTA) for four days], then processed [Ethanol series (50°–80°–90°–99°–99°,

45 minutes each; Xylene three times, 45 minutes each; Paraffin 56°C, three times, 45 minutes each], embedded in paraffin and then 2 µm cross-sections were stained with Hematoxylin and Eosin (HE), Dane trichrome and Periodic Acid–Schiff (PAS).

Soft tissue samples were fixed in 10% buffered formalin, processed [Ethanol series (50°–80°–90°–99°–99°, 45 minutes each; Xylene three times, 45 minutes each; Paraffin 56°C, three times, 45 minutes each], embedded in paraffin and then 2 µm cross-sections were stained with HE, Dane trichrome and PAS.

The cross-sections were observed with Labomed USA microscope (4×–10×–40×).

Results

We observed that on soft tissue the cavity shape performed by laser (QSP mode) is well preserved. The model is characterized by a net and clear border from the top to the bottom between the cavity and the muscular fibrocells, which are typical for the tongue bovine model that was used. They are not evident any kind of alteration of the normal histological structures. This is clearly related to the physical effects of QSP mode (Figure 3).

In the cavity sealed with silicone, we notice the presence of debris and blood cells both in holes performed with laser and bur. There is a clear evidence of bone spicule with proper lacunae, blood cells with and without nucleus in degradation. Spicule seems to be in part detached from the proper bone and in part still attached. This can be probably related to the mechanical stress, which was induced by drilling (Figure 4). In Figure 5, there is an evidence of eosinophilic spicule and more basophilic blood cells and debris within them. The persistence of the debris could be related to the activity of the silicone tap that avoid a possible cleaning process during histological sample preparation.

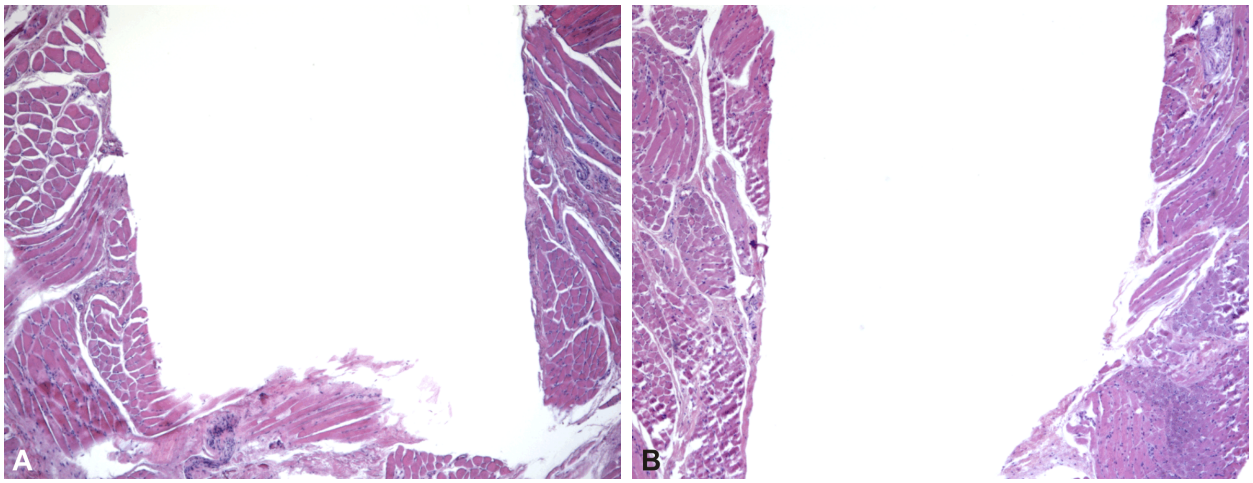

Figure 3 – ***(A and B) Well preserved shape of the cavity (up upper part and bottom lower part of the cavity) in a soft tissue model with laser (QSP mode) preparation sealed with silicone before histological processing. HE staining, ×40. QSP: Quantum square pulse.***

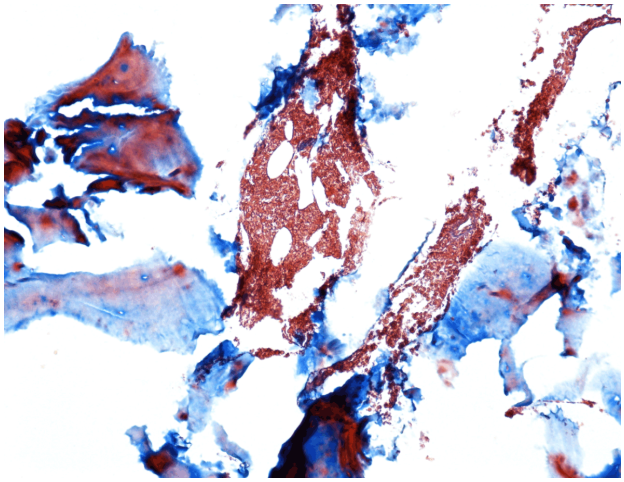

Figure 4 – ***Bottom of the cavity (bur with silicone) in bone demonstrating the presence of debris (blue) and blood cell (red) in the cavity sealed with silicone before histological processing. Goldner–Szekely (GS) trichrome staining, ×100.***

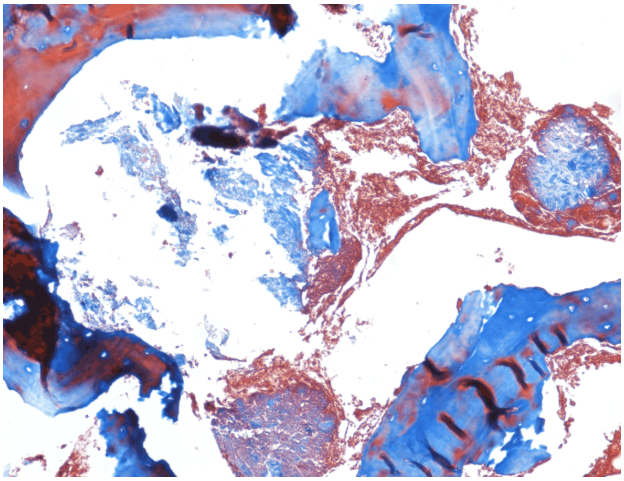

Figure 5 – ***Bottom of the cavity (laser with silicone) in bone demonstrating the presence of debris and blood cell inside lacunae of the bone but not in the cavity sealed with silicone before histological processing. GS trichrome staining, ×100.***

In soft tissue, we also noticed a thermal effect due to laser used in MAX mode. In particular, we noticed a continuous collagenization of the surface cavity, as shown in Figure 6, a bluish tissue near the cavity where the normal tissue organization is lost. Photothermal and photochemical activity was highlighted when using MAX mode in tongue muscle. Eosinophilic fibers with nuclei in partial degradation (basophil) and evidence of thermal effect with thermal fiber damage (eosinophilic) at the border between cavity and tissue were observed in Figure 6. On the contrary, this thermal effect was not observed in those holes performed in QSP mode (Figure 7). This different thermal effect is probably due to a different use of air/water ratio in the in the MAX and QSP mode (Figures 8 and 9). Figure 9 shows that photothermal and photochemical activity in QSP mode seems to be absent or quite insignificant. Eosinophilic fibers with nuclei in partial degradation (basophil) and lack of evidence of thermal effect or thermal fiber damage (eosinophilic) at the border between cavity and tissue where the basophilic line is not evaluable.

Gutknecht *et al.* [18] explain very accurate the benefits of QSP mode, which provides a longer laser pulse divided, *i.e.*, into several short pulses, at an optimally fast rate. The results of this technology involves delivering short, high finesse pulses with the efficiency of long duration laser pulses and reducing simultaneously the undesirable effects of laser beam scattering and absorption in the debris cloud during hard tissue ablation. Using this laser mode, they resulted sharp and well-defined cavities, with minimal thermal effects at the edges. Therefore, it is considered that QSP mode provides an additional high finesse treatment modality. When QSP modality is used, the average repetition rate of Er:YAG lasers can be easily increased to 120 Hz and above, thus providing an optimal solution for reducing the undesirable effects of debris screening without significantly affecting the available range of laser power.

Moreover, we observed also that the use of silicone for sealing the cavity after preparation is clearly important in maintaining debris and the shape of the cavity itself (Figures 10–14).

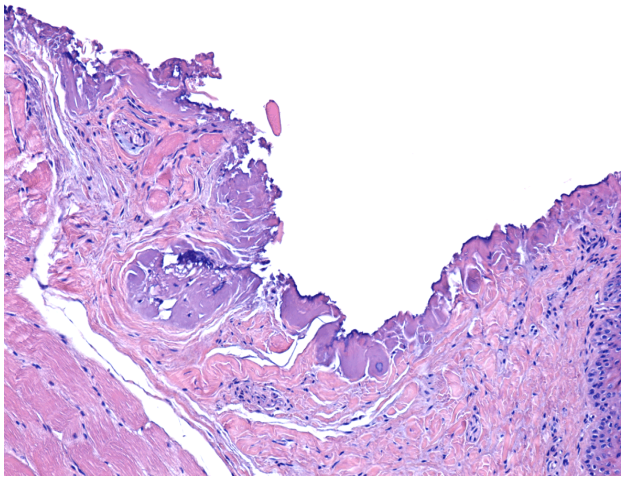

Figure 6 – ***The darker part shows the thermal effect of laser preparation in a soft tissue model (laser MAX mode with silicone). HE staining, ×100.***

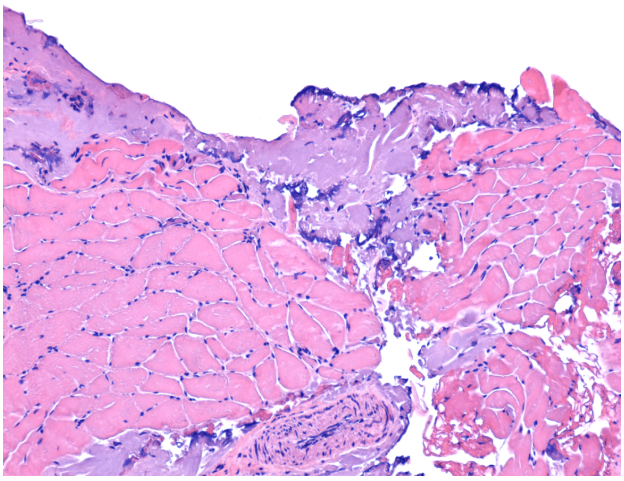

Figure 7 – ***The darker part shows the thermal effect of laser preparation in a soft tissue model (laser MAX mode with silicone). HE staining, ×100.***

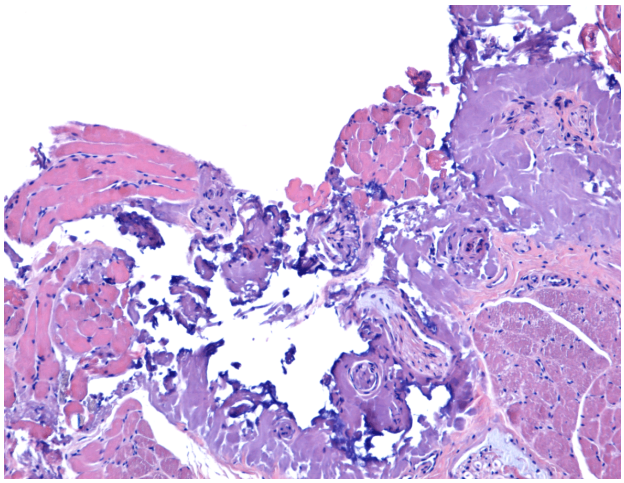

Figure 8 – ***The darker part shows the thermal effect of laser preparation in a soft tissue model (laser MAX mode with silicone). HE staining, ×100.***

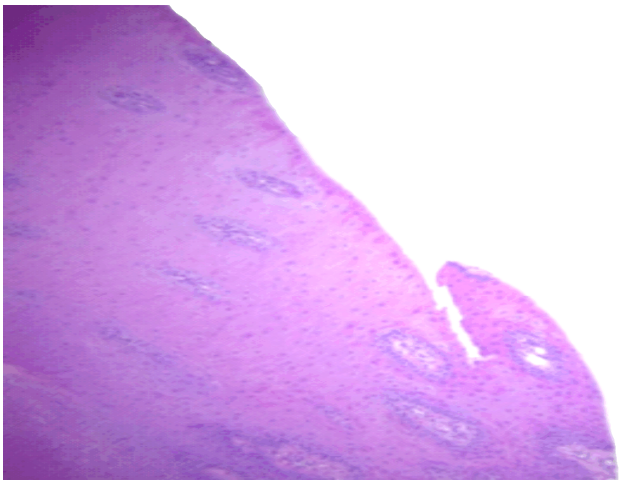

Figure 9 – ***Absence of the thermal effect using laser for the preparation in a soft tissue model (laser QSP mode with silicone). HE staining, ×40. QSP: Quantum square pulse.***

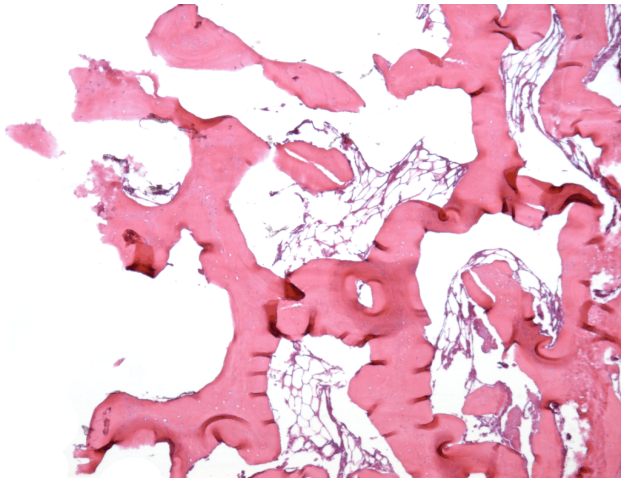

Figure 10 – ***Bottom of the cavity (bur without silicone) in bone. Bone without silicone shows irregular shape of the bottom of the cavity with fewer blood cells and few bone debris. HE staining, ×100.***

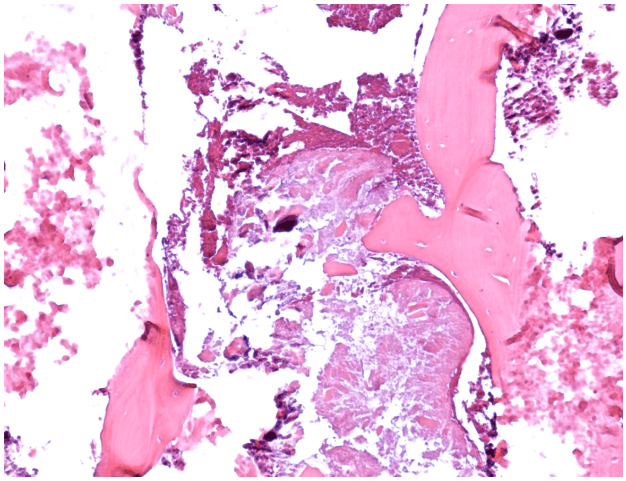

Figure 11 – ***Bottom of the cavity (bur without silicone) in bone shows destruction of the bone lamellar structure. HE staining, ×100.***

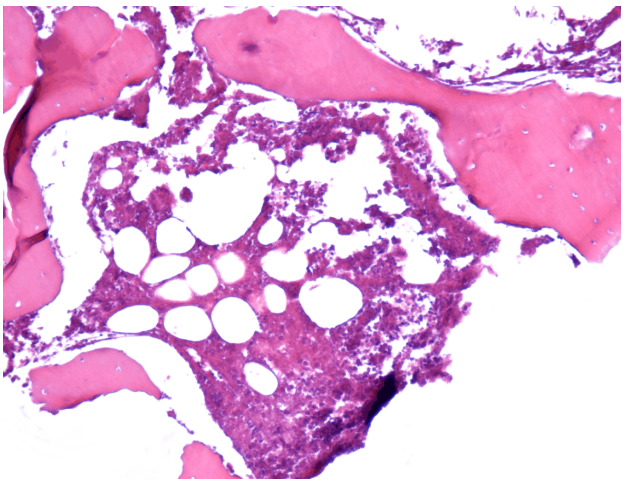

Figure 12 – ***Bottom of the cavity (bur without silicone) in bone shows absence of blood cells in red, connective, and soft tissue debris in blue empty lacunae. HE staining, ×100.***

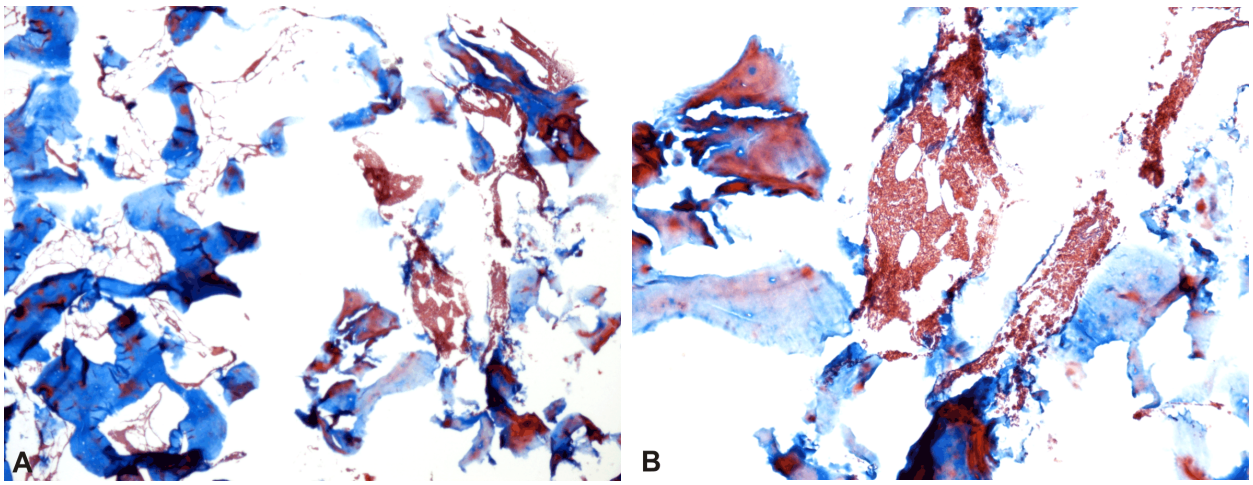

Figure 13 – ***(A and B) Bottom of the cavity (bur with silicone) in bone are present of blood cells (red) and connective tissue debris (blue) in the cavity and in lacunae. GS trichrome staining, ×100.***

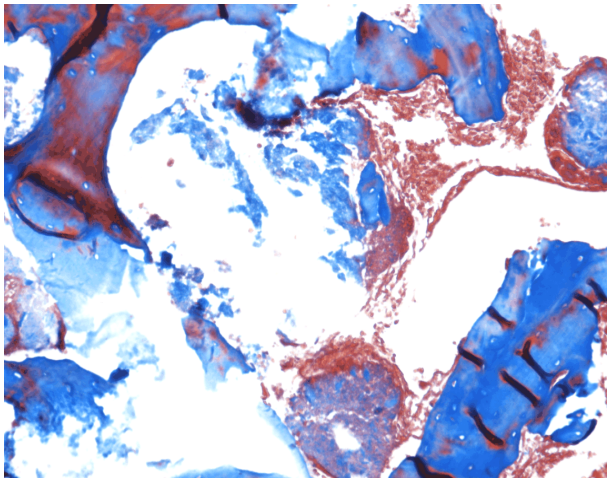

Figure 14 – ***Bottom of the cavity (laser with silicone) in bone are present of less blood cells in (red) and less connective tissue debris (blue) in lacunae. GS trichrome staining, ×100.***

Discussions

Overall, our results suggest that silicone sealing is necessary to maintain the shape of the cavity and the debris inside the cavity prepared using all the devices. Differences in using or not the silicone are significant. Indeed, we show that silicone is fundamental in order to measure correctly the shape of the cavity.

The thermal effect is present on soft tissue using MAX mode, but absent when using QSP mode. It was not possible to evaluate the thermal effect on bone tissue, but logically would be transferred to it. Using MAX mode, the thermal effect is strictly connected with the settled air/water ratio. The thermal effect will be greater with the increasing of water. For this reason, it is recommended to use an appropriate air/water ratio during the cavity preparation. An interesting review was publish by Möhlhenrich *et al.* [19], which tried to identify the factors that influence the drilling effects during implant bed preparation. A number of factors can influence the heat generated during drilling at the implant site, such as: the operating technique (pressure, movement, speed, and duration of drilling), the design and sharpness of the drill, irrigation system, and implant system, the local site conditions and the patient condition (age and bone density). Results of the study showed, regarding the diameter of the drill, that a 2 mm diameter drill causes higher temperatures than sequential drills with conical burs. The shape of the bur also influences the tissue heating, whereas the material has no obvious influence in this regard. Drill load and drill wear also seemed to influence the thermal effects.

In all bur samples were present more debris and more blood cells than in laser samples. According to the rules of healing processes, this can be a negative factor for the osseointegration process and the time for the formation of the woven bone related with the shift from primary stability to the biological stability in implantology. For this reason, probably, use of laser to prepare the implant site without debris formation, can be convenient to decrease healing time. Nowadays, is not still present a laser device that can overtake the technical limitations of the laser scanner (*i.e.*, deepness control and scanner movement during the preparation of the holes, etc.).

The importance of a very good rinsing of the implant site can be discussed before placing the fixture, due to the creation of debris during the traditional bur preparation.

The problem to have a scanner laser handpiece that allow a creation of a repeatable site has to be solved. The problem of controlling the deepness of the site and the shape are not yet solved. Nowadays, is not possible to move the scanner handpiece during the preparation because is not possible to be sure to put it again in the same position. Regarding this problem, Seymen *et al.* [20] conducted an *in vivo* study on sheep inferior jaws, investigating the implant bed preparation using erbium, chromium-doped yttrium, scandium, gallium garnet (Er,Cr:YSGG) laser and stereolithographic (SLA) surgical guides. Their results showed that implant site can be properly prepared with Er,Cr:YSGG laser system using surgical guide, thus being an alternative to conventional drilling method.

Our study demonstrated that using this new QSP mode of ER:YAG laser there are not evident any kind of alterations of the normal histological structures in soft and hard tissues, whilst using MAX mode photothermal and photochemical activity was highlighted. Moreover, due to the insufficient number of experimental and clinical study, the laser still is not considered the first choice in implant bed preparation.

Conclusions

Conventional preparation with bur generated more debris and more blood cells than in laser samples, which can be a negative factor for the osseointegration process. Using QSP mode showed good results regarding reduction of thermal effects and obtaining well-defined cavities. Overall, this study suggests that laser may be a useful device to create an implant site for patients receiving prosthetics on implants.

Complete financial disclosure/Conflict of interests' statement

The authors individually declare that they have no financial or other type of conflict of interests regarding the research or commercial products presented in this paper.

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