EXPERIMENTAL STUDY ON THE EFFECT OF Nd:YAG LASER ON DENTAL HARD TISSUE: COMPARISON BETWEEN MULTI-PULSE AND FREE-GENERATION MODES

ESTUDIO EXPERIMENTAL DEL EFECTO DE UN LÁSER Nd:YAG SOBRE EL TEJIDO DENTAL DURO: COMPARACIÓN ENTRE LOS MODOS DE GENERACIÓN MULTI-PULSO Y LIBRE

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The goal of the present study is to compare the morphological changes in dental hard tissue that are obtained through the use of passively Q-Switched multi-pulse Nd:YAG laser irradiation, with a free-generation mode Nd:YAG laser. The experimental samples consisted of six healthy third molars that were divided equally and randomly for the two irradiation methods. The depth of each perforation was quantified using optical coherence tomography (OCT). The highest fluency and the shortest duration of the pulses obtained by the multi-pulse laser with a Q-switch allowed for more efficient ablation of the dental material than what was obtained via the free-generation mode.

El objetivo del presente estudio es comparar los cambios morfológicos en el tejido dental que se obtienen mediante irradiación con láser de Nd: YAG en modo multi-pulso con Q-Switched pasivo y láser Nd: YAG en modo de generación libre. Las muestras experimentales consistieron en seis terceros molares sanos que se dividieron igualmente y aleatoriamente para los dos métodos de irradiación. La profundidad de cada perforación se cuantificó utilizando la tomografía de coherencia óptica (OCT). La fluidez más alta y la duración más corta de los pulsos obtenidos por el láser de Nd: YAG en modo multi-pulso con Q-Switched pasivo permitió una ablación más eficiente del material dental que la obtenida mediante el modo de generación libre.

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I. INTRODUCCIÓN

Since its inception in 1960, laser irradiation has facilitated myriad medical and dental treatments. Pioneers in the field of dentistry (Fisher and Frame in the United Kingdom, Pecaro and Pick in the United States, and Welcer in France), proposed the use of CO_2 lasers in soft tissue surgeries. Melcer also began to conduct these applications in hard tissues. Recent developments in laser dentistry have led to its approval for various dental treatments, being accepted by dentists and patients [1].

There are two classes of lasers that are employed in the medical field, namely: high-power lasers (surgical applications), and low-power lasers (therapeutic applications). Nd:YAG lasers fall within the first group, emitting its power within the infrared range. In the dentistry field, it is primarily used in periodontics and endodontics, due to its efficacy in the elimination of microorganisms [2,3].

An average absorption at 1064 nm wavelength, corresponding to the Nd:YAG laser has been reported. In order to enhance laser penetration, studies have employed dyes to treat samples prior to irradiation [4,5]. The precise control of laser-initiated temperature in dental tissues is of the utmost importance, as it may cause irreversible pulp damage beyond certain limits [6]. Three methods have been proposed to prevent excessive temperature increases, namely: (a) pulse duration should be less than the time constant of thermal relaxation of the dental material; (b) the pause between pulses should be greater than the time of thermal relaxation to allow the proper cooling of the material; and (c) refrigerated water irrigation of irradiated areas should be used to reduce the temperature [7,8]. Previous studies that have assessed the use of Nd:YAG lasers in dentistry have reported its use in continuous and pulsed regimes, the latter of which has two variants: free-generation and Q-switch.

The first variant generates pulses with durations within the range of from between 0.1 and several milliseconds, which tends to initiate perceptible thermal effects. The second variant has much shorter pulse duration, within the nanosecond range. However, its thermal action is quite limited, as is the speed of material extraction. Consequently, the cost of the equipment is higher [4,9].

A particular Q-switch regime that has been used more recently is referred to as multi-pulse. The pulse or laser shot, which lasts from tens to hundreds of microseconds, actually consists of a group of pulses, each of which has 10 to 30 ns duration. This type of laser uses a passive Q-switch, based on a Cr: YAG crystal, which is much more simple and robust than the electro-optically based switches that are used in mono-pulsed lasers. It also allows for cheaper and more compact laser irradiation [10]. Multi-pulsed lasers based on passive switches have been used in applications such as pulsed laser deposition [11], the selective treatment of biomaterials or food [12], and recently, as a component of laser-induced plasma spectroscopy [13,14].

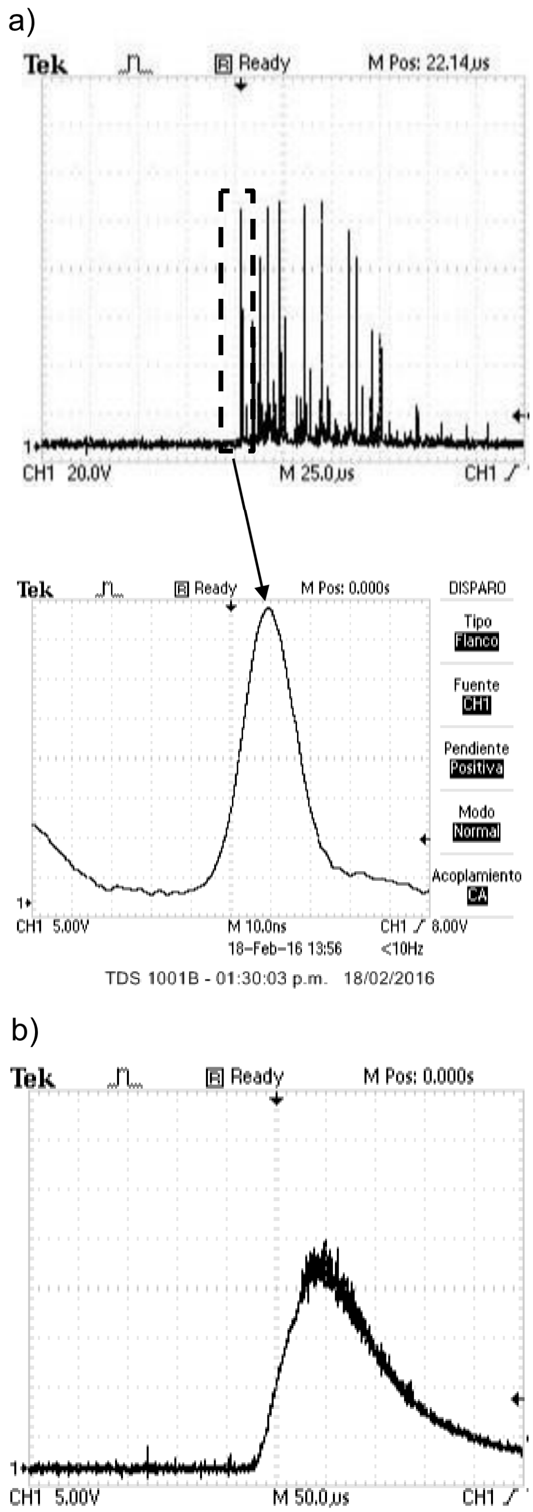

Figure 1. (a) Temporal profile of the laser shot in multi-pulse regime. The insert above, reveals the details of a single micro-pulse, and (b) one of the pulses in the free-running regime.

To date there have been no investigations into the effects of multi-pulse Nd:YAG laser irradiation on dental materials. The goal of the present study was to determine and compare perforation speeds and morphological changes in dental structures following Nd:YAG laser irradiation using free-generation and multi-pulse modes. The latter mode might offer significant advantages, such as decreasing the thermal effects of lasers that operate in the free generation mode, thus maintaining a suitable perforation speed for laser systems that are employed in dentistry.

We conducted a comparative study between multi-pulse and free-generation regimes that were used to perforate healthy molars. The results were confirmed by means of optical coherence tomography (OCT).

II. METHODS

II.1. Study Sample

The samples consisted of six healthy third molars, which were donated by the School of Dentistry of the Autonomous University of Tamaulipas. The molars underwent two longitudinal cuts on opposite sides to obtain dentin tissue exposure and an area free of irregularities, as well as to maintain a constant distance between the samples and the lens with the lowest possible variation. The samples were immersed in water and placed in an ultrasonic cleaner (Branson 1510), at a temperature of 27°C for 15 minutes. Subsequently, they were placed in a specimen holder at a regular distance of 1 cm.

II.2. Instruments used in the experiment

We employed a multi-pulse Nd: YAG laser with Cr:YAG as a passive Q-switch. This laser emitted a wavelength of 1064 nm and was supplied by Bralax Company. In this irradiation regime, each laser shot consisted of a train of pulses with a total duration of approximately 75 μs (FWHM), and a configurable energy that ranged from 60 to 380 μJ. Each shot consisted of a total of pulses that varied from 15 to 25 with a duration of 30 ns each (see figure at top left). The oscillograms of Figures 1a and 1b illustrate the form and duration of a single shot, and one of the pulses that forms it, respectively.

The removal of the Cr:YAG crystal from the cavity allowed the laser to irradiate in the free-generation regime. Each shot was approximately 250 ns in duration, with energies that ranged from 280 to 830 μJ. The oscillogram of Figure 2 illustrates the form and duration of a single shot in this generation mode. For the two generation modes, we employed a 5-cm focal-length lens, which produced a spot of approximately 0.5 mm in diameter on the surface of the sample.

The form and depth of each perforation was determined by means of OCT. Spectral domain optical coherence tomography (SD-OCT) is a measurement method that is based on the detection of differences in the optical path length. This technique incorporates a light source with a wide spectrum, and a spectrometer, to recreate depth profiles that are achieved by cross-sectional imaging, which can be used to display three-dimensional reconstructions. This measurement method reconstructs images of the voids that are generated by laser ablation, in order to observe changes in the samples. The equipment used was the CALLISTO system, Thorlabs, whose central wavelength was 930 nm and maximum depth resolution was 1.6 mm. We used a PDA10A photodetector (Thorlabs Inc.) and a TDS1001b oscilloscope (Tektronix®) to obtain the temporal profiles of the shots in the two regimes.

II.3. Description of the experiment

The samples were divided equally and randomly for the two irradiation methods. We performed five perforations in the dental tissue at a regular distance of 1 mm, with a difference of five shots with respect to the next sample, up to a total of 25 shots. The shots were made into the dentin of the coronal portion of the teeth, between the enamel coat and the pulp cavity, and horizontal to the longitudinal axis of the teeth (Figure 2). The approximate energy density of the multi-pulse and the free-generation laser shots were 36 J/cm^2 and 10^5 J/cm^2, respectively.

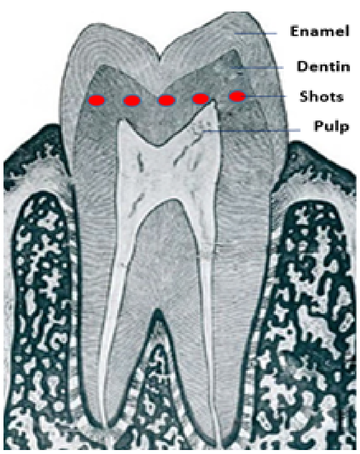

Figure 2. Experimental scheme of the sample. Longitudinal cut of a tooth extracted with the shots performed

We performed the characterization of the perforations through images obtained by optical microscopy at 50X magnification. Additionally, we obtained images of the cavities profiles using the OCT technique. Figure 3 illustrates the profiles of the perforations carried out with the two methods.

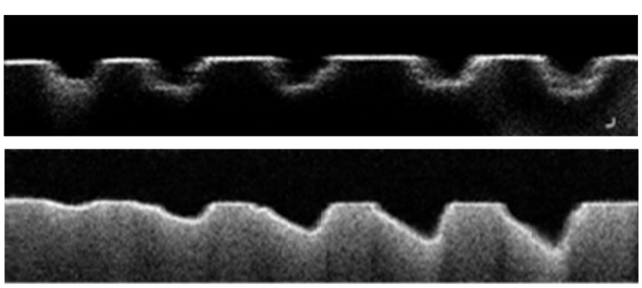

Figure 3. OCT imaging of the perforation profiles: (Top) multi-pulse mode, (Bottom) free-generation mode.

III. RESULTS AND DISCUSSION

Figure 4 shows that the depth of the cavities were typically greater after the first M. At one point, between 15 and 20 shots, the depth obtained by the free-generation mode was greater than that obtained by the multi-pulse mode and, in general, the perforation speed obtained was greater. This result was due to the fact that the energy was greater in the free-generation mode. It is important to emphasize that although these shots were made using different energy levels, the power consumption of the laser remained constant, since, as it is known, the use of a Q-switch generates losses of energy in the irradiation compared with the free-generation mode. It is worth mentioning that when we used the same energy level of the multi-pulse mode in the free-generation mode, we did not obtain any ablation. This result indicated that the absorption by the material was more efficient using the multiple Q-switch laser pulses. This results from achieving higher fluencies that exceed the rupture threshold of the material more easily, with energy similar to that used in the free-generation mode.

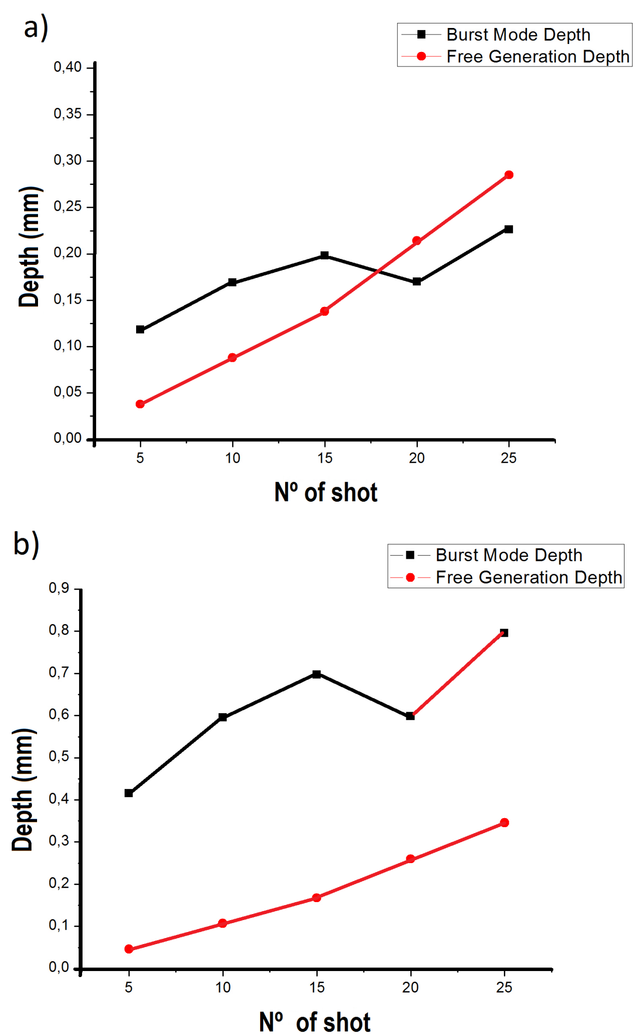

Figure 4. Results obtained in void depth versus number of pulses, with the two methods contrasted (a) and normalised with their respective energies (b).

In order to compare the effects of the two methods, despite using different energies, we obtained the relationship of each depth with their associated energy. Figure 4b reveals the experimental results and trend lines. An extraction speed of similar material can be observed in the two generation modes. However; the experiment indicated that greater depths were obtained in the multi-pulse mode at the same energy levels.

In addition to the depth that may be obtained with one laser mode or the other, the quality of the perforation, damage to the surrounding tissue, and the temperature to which the dental material is submitted are of the utmost importance. In order to qualitatively assess this aspect, we obtained images via optical microscopy at 50X magnification (Figure 5).

There was clear evidence of greater thermal effect on the perforations made in the free-generation mode due to greater duration of the pulses. High temperatures achieved greater tissue calcination in this mode, a result that had already been reported in previous studies [15].

Further, it should be noted that the Nd:YAG laser in free-generation mode melted the material surrounding the perforations, and created edges of melted material deposited around them.

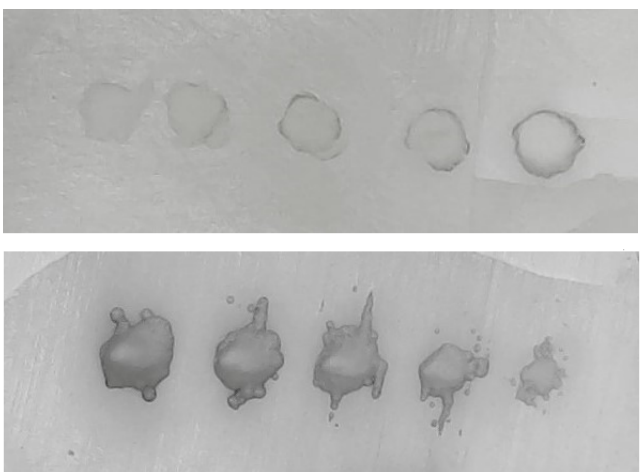

Figure 5. Images obtained by optical microscopy at 50X magnification: a) multi-pulse mode; b) free-generation mode.

IV. CONCLUSIONS

The highest fluency and the shortest duration of the pulses obtained by a multi-pulse laser with a Q-switch enabled more efficient ablation of the material than that obtained in the free-generation mode.

On the other hand, the quality of the voids characterized by the non-existence of remains or edges caused by the ablation process were obviously improved as a result of the multi-pulse mode, which was an expected result due to shorter duration of the pulses and, therefore, heat transfer with a consequent thermal effect. If we take into account that multi-pulse irradiation was obtained using a Q-switch, which is characterized by its simplicity, low cost and robustness, the potential of using this laser emission regime in dentistry becomes evident.

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REFERENCES

[1] R. M. Pick, J. Am. Dent. Assoc. 124, 37 (1993).

[2] A. J. España-Tost, J. Arnabat-Domínguez, L. Berini-Aytés, and C. Gay-Escoda, RCOE 9, 497 (2004).

[3] D. Zavaleta-de la Huerta, A. J. España-Tost, L. Berini-Aytés, and C. Gay-Escoda, RCOE 9, 539 (2004).

[4] A. McDonald, N. Claffey, G. Pearson, W. Blau, and D. Setchell, Biomaterials 23, 51 (2002).

[5] A. Mehl, L. Kremers, K. Salzmann, and R. Hickel, Dent. Mater. 13, 246 (1997).

[6] L. Zach and G. Cohen, Oral Surgery, Oral Medicine, Oral Pathology 19, 515 (1965).

[7] T. J. Flotte, R. Anderson, and T. F. Deutsch, Lasers Surg. Med. 8, 108 (1988).

[8] C. T. Vangsness, T. Watson, V. Saadatmanesh, and K. Moran, Lasers Surg. Med. 16, 61 (1995).

[9] A. V. McDonald, N. M. Claffey, G. J. Pearson, W. Blau, and D. J. Setchell, Lasers Surg. Med. 27, 213 (2000).

[10] T. Flores, L. Ponce, M. Arronte, and E.DePosada, Opt. Lasers Eng. 47, 578 (2009).

[11] T. Garcia, J. Sanchez, S. Diaz, L. Ponce, E. Estevez, J. Pena, P. Bartolo, and M. Farias, Mater. Lett. 28, 65 (1996).

[12] L. Ponce, T. Flores, M. Arronte, V. Parfenov, L. Koval'chuk, and L. Bartoli, J. Opt. Technol. 75, 490 (2008).

[13] F. Alvira, T. F. Reyes, L. P. Cabrera, L. M. Osorio, Z. P. Baez, and G.V. Bautista, Appl. Opt. 54, 4453 (2015).

[14] L. M. Osorio, L. V. P. Cabrera, M. A. A. García, T. F. Reyes, and I. Ravelo, J. Phys.: Conf. Ser. 274, 012093 (2011).

[15] H. Wigdor, E. Abt, S. Ashrafi, and J. T. Walsh, J. Am. Dent. Assoc. 124, 65 (1993).