Article

Dentine Laser Welding: A New Help for Fractured Teeth? A Preliminary Ex Vivo Study

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Abstract: An important surgical goal is to provide a first intention wound healing without trauma produced by sutures and for this aim in the past several methods have been tested.
The aim of this preliminary *ex vivo* study is to demonstrate the capacity of a 1070 nm pulsed fiber laser to treat the dental fractures by dentine melting with the apposition of hydroxyapatite nanoparticles as filler.
Only the specimens of the group b showed a real process of welding of the two parts, while specimens of groups a and c did not reach a complete welding process.
Out of thirty freshly-extracted human third molars, decay-free, twenty-four cylinders of 5 mm thickness were obtained to perform the test.
The device used was a 1070 nm Yb-doped pulsed fiber laser: this source has a maximum average output power of 20 W and a fixed pulse duration of 100 ns, while the repetition rate ranges from 20 kHz to 100 kHz.
The samples were divided in three groups (a, b, c) of eight teeth and each specimen, with the two portions strictly placed side by side, was put inside the box and irradiated three times, the first and the second at 30 kW and the last at 10 kW power. The frequency was maintained at 20 kHz for all the tests as well as the speed of the beam at 10 mm/sec.
The samples of the group a were irradiated without apposition, in the group b nanoparticles (<200 nm) of hydroxyapatite were put in the gap between the two portions while in the group c, a powder of hydroxyapatite was employed.
Only the specimens of the group b showed a real process of welding of the two parts, while specimens of groups a and c did not reach a complete welding process.

Keywords: Dentine; welding; fiber laser.

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1. Introduction

An important goal of the experimental and clinic surgery is the reaching of a real tissue welding to provide a first intention wound healing without having the trauma produced by using sutures.
In the last years several methods were proposed, based on high-frequency electric charge [1, 2], chemical adjuvants [3], plasma application [4] and laser irradiation also with filler nanoparticles [5, 6].
The most important applications of laser tissue welding regard up today the fields of ophthalmology [7, 8], general [9] and vascular surgery [10], ENT [11], dermatology [12] and dentistry [13] but all the studies are limited to the soft tissues irradiation.
One of the unsolved problems in daily dental practice concerns the treatment of the longitudinal fractures of the teeth causing, in the most part of the cases, as final result, the extraction of the involved tooth: for this reason, the possibility of enamel and dentine laser welding seems to open interesting perspectives.

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The aim of this preliminary *ex vivo* study is to demonstrate the capacity of a 1070 nm pulsed fiber laser to treat the dental fractures by dentine melting with the apposition of hydroxyapatite nanoparticles as filler.

2. Results

All the observed samples showed large zones of carbonization associated to areas of dentine melting.
Only the specimens of the group b showed a real process of welding of the two parts (Figures 1-3), while specimens of groups a and c (Figure 4) didi not reach a complete welding process.

2.2. Figures, Tables and Schemes

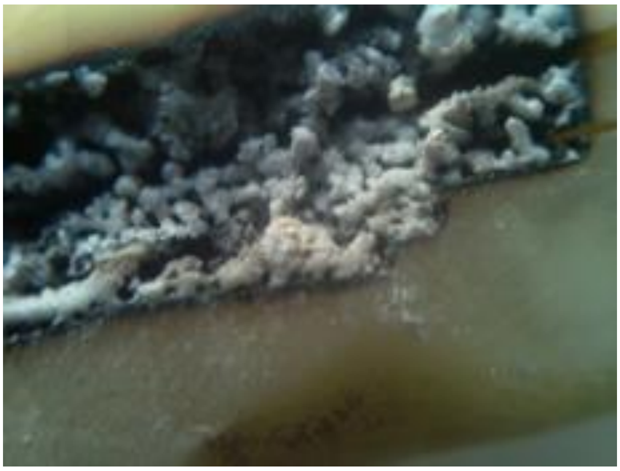

Figure 1. We-LAB observations of a sample of group b: it maybe appreciated the melting process of dentine with a bridge between the 2 parts (magnification x40).

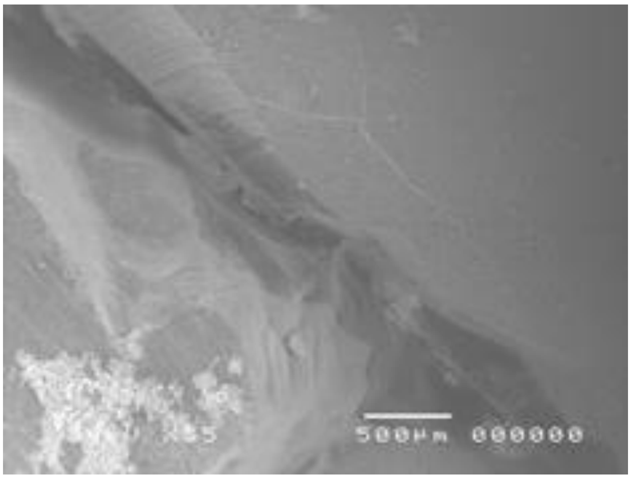

Figure 2: SEM observation at magnification of 35x of a sample of group b with dentine welding.

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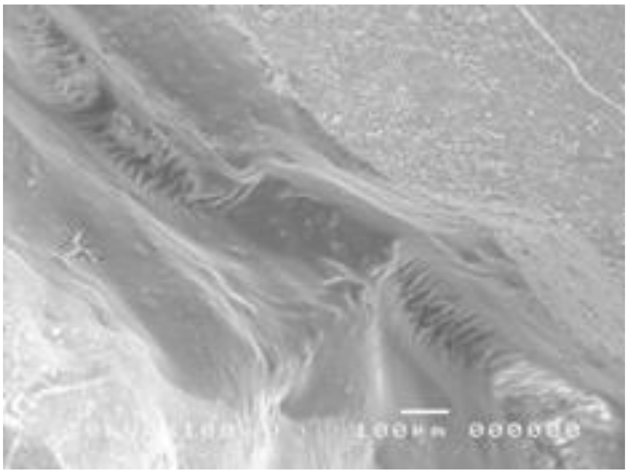

Figure 3: SEM observation at magnification of 100x of a sample of group b with dentine welding bridge within the 2 dental parts.

Figure 4: Optical view of a not complete welded sample of group c.

Figure 5: setup of the study with cilinders before cutting (left), after cutting (middle) and ready for being processed (right).

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Figure 6: 1070 nm Yb-doped pulsed fiber laser (AREX 20, Datalogic, Italy).

3. Discussion

The field of the biological tissues laser welding is full of publications related to the soft tissues only, particularly on vessels, where different laser wavelengths were used.

Nakadate et al [14], by adding the preloaded longitudinal compression on the coapted vessel edges to a 970-nm diode laser irradiation, obtained a significant increasing of their strength, so avoiding the use of suture.

Jain and Gorisch [15] obtained interesting results in the treatment of small vessels (0.3/1 mm diameter) by using Nd:YAG laser while Lèclere et al described, in a total of 40 clinical procedures, great successes reached by the utilisation of 1950nm diode laser [16].

The laser welding process, as described by Wolf-de Jonge [17], is provoked by the laser energy which causes an alteration in protein structure of tissues, resulting in repair through cross bonding of proteins; in the same study it was underlined the importance, for the welding success, of the correct choice of laser wavelength, as well as, of the proper parameters (power, power density and/or spot size, and time of exposure) and also of the utilisation of solders which consist of a protein or protein-like substance applied to the weld to enhance bonding.

Gerasimenko [18] proposed, for the welding of biological tissues using laser device the utilisation of nanocomposite solders, while Strassman [8] demonstrated the employment of the CO2 laser coupled to albumin solder in the reparative surgery of the cornea.

Semenov [19] described the tissue welding for the ossiculoplasty by associating the laser irradiation to the application of platelet-rich plasma (PRP) as a solder alloy.

In 1984, Almquist et al [20] first reported the use of an argon laser in peripheral nerve repair in both rats and monkeys. The following year, Fischer et al [21] published similarly positive reports with the use of the carbon dioxide laser for nerve repair in rats.

Bloom, by an "in vivo" study performed in rabbits where a facial nerve injury was followed by either standard suture neurorrhaphy or laser tissue welding [22], demonstrated that laser tissue welding repair trended toward superior outcomes compared with suture neurorrhaphy at all 4 time points and the result was reached by the utilization of a combination of the 810-nm diode laser and a 42% albumin solder doped with an indocyanine green chromophore.

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In this study we tested the possibility of obtaining a real dentine welding by the melting of the hard dental tissues provoked by the laser irradiation associated to the hydroxyapatite nanoparticles apposition.
It is important to underline that a pilot study performed on the same kinds of samples here used demonstrated that different wavelengths and different parameters provoke only large zones of vaporization and carbonization and very small areas of melting, this being not sufficient for reaching the result of welding.
A great role in the dentin welding process may be played by the pulse duration of 100ns: in fact, this very short parameter may be responsible of the avoiding the possibility of carbonization.
Even if in this study the evaluation was only based on the microscopic observation, and for this reason it must be considered as preliminary, nevertheless it opens a new perspective for the treatment of fractured teeth which, at the moment is not easy by a clinical point of view.
This approach will have to be confirmed by further works based on the strength of the joint (traction tests), the chemical composition of the joint (X-ray Electro-dispersive Analysis) and the thermal elevation during the irradiation (Fiber Bragg Grating) to verify if it may be transferred to the clinic for the treatment of the traumatic injured teeth.

4. Materials and Methods

Thirty freshly-extracted human third molars, decay-free, were used for this study.
They were stored in 0.5% chloramines solution before the experiment to inhibit microbial growth for 1 h until being ready for use. They were maintained for a maximum of 10 days before the tests in those conditions and then placed in distilled water according to ISO standards 11405. Only dental caries free teeth were selected and, before the experiment, the teeth were cleaned with ultrasonic scaling. Teeth labial surfaces of the crowns were polished using pumice and water slurry in a rubber cup. Then the teeth were rinsed with water for 15 seconds and blown dry with oil-free compressed air (Cattani Compressor, Parma, Italy). The teeth with defects were removed and, at the end, twenty-four cylinders of 5 mm thickness were obtained they were polished and stored in distilled water at room temperature until the performing of the test.
All the samples were grinded on their vestibular and buccal sides for obtaining a smooth surface and, subsequently, cut, by a steel disc, perpendicularly to the plane face to obtain, by each specimen, two parts which, subsequently, were perfectly put near each other (Figure 5).
The device used was a 1070 nm Yb-doped pulsed fiber laser (AREX 20, Datalogic, Italy): this source has a maximum average output power of 20 W and a fixed pulse duration of 100 ns, while the repetition rate ranges from 20 kHz to 100 kHz. By a dedicated software, it is possible to determine in advance the shape and the dimension of the irradiation area (line, square, etc), as well as the number of passages. The device is contained in a safety box to assure an effective protection to the operator (Figure 6).
By means of a pilot study it was noticed that the output power able to produce a great melting of the dental tissue with the minimal carbonization was around 30 kW at a Repetition Rate of 20kHz and with a speed of the beam of 10mm/sec. in focused mode.
Each sample was processed in a rectangular zone, between the two parts using a meshed filling pattern with a distance between lines of 0.03 mm.
The samples were divided in three groups (a, b, c) of eight teeth and each specimen, with the two portions strictly placed side by side, was put inside the box and irradiated three times, the first and the second at 30 kW and the last at 10 kW power. The frequency was maintained at 20 kHz for all the tests as well as the speed of the beam at 10 mm/sec.
The samples of the group a were irradiated without apposition, in the group b nanoparticles (<200 nm) of hydroxyapatite (Sigma Aldrich, USA) were put in the gap between the two portions while in the group c, a powder of hydroxyapatite (Sigma Aldrich, USA) was employed.
The teeth were observed at two different magnifications (40× and 100×) under low and high-power light microscopy (Nikon Lab Phot, Japan) and by a new device running through a smartphone (We-LAB, DNAphone®, Italy); after metallization, it was also observed by Scanning Electron Microscope (Ion sputter Jeol JFC 1100E, USA).

5. Conclusions

This *ex vivo* preliminary study, based on the dentin welding obtained by a 1070nm pulsed fiber laser associated to the hydroxyapatite nanoparticles, may represent a new and original approach for the treatment of the fractured teeth, even if further studies will be necessary to confirm these results.

6. Patents

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