Hard dental tissues laser welding: a new help for fractured teeth? A preliminary ex vivo study

Carlo Fornaini 1,2, Elisabetta Merigo 2, Federica Poli 1, Jean-Paul Rocca 2, Stefano Selleri 1, Giuseppe Lagori 2, Annamaria Cucinotta 1

1: Department of Engineering and Architecture, University of Parma, Parco Area delle Scienze 181/A, 43124 Parma, Italy
2: Micoralis Laboratory, Faculty of Dentistry, University of Cote d’Azur, 24 Avenue des Diables Bleus, 06357 Nice, France

Background and Aim: 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 ex vivo preliminary study was to demonstrate the capacity of a 1070 nm pulsed fiber laser to treat the dental fractures by enamel and dentine melting with the apposition of hydroxyapatite nanoparticles as filler.

Methods: 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 peak power (average powers of 60 and 20 W). The repetition rate 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.

Results: 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.

Conclusion: This ex vivo preliminary study, based on the enamel and dentine welding obtained by a 1070 nm 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.

Key words: Enamel • Dentine • Welding • Hydroxyapatite • Fiber laser • Nanoparticles.

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.

The difficulty to weld hard dental tissues is due, for the majority, to its chemical composition which is consti-
tuted by water and hydroxyapatite with absorption peaks, respectively, at 3000 and 2800 nm (Fig. 1).

This is the reason of the utilization in dentistry, for hard tissues ablation, of the “erbium family” lasers (Er:YAG and Er, Cr:YSGG) emitting in this range of wavelengths.

In the case of welding, however, the required effect is totally different from the ablation, consisting in the formation of a great quantity of melted tissue, able to form a bridge between the two parts of the tooth.

So, a Nd:YAG laser with very short pulse duration has been chosen, based on the great number of studies in literature 14-17).

In fact, all these studies showed that this wavelength, when emitted at pulse durations of ns and ps, is well absorbed by the dental hard tissues.

The aim of this preliminary ex vivo study is based on the hypothesis about the capacity of a 1070 nm pulsed fiber laser emitting ns pulses to treat, at proper parameters, the dental fractures by dentine melting obtained with the apposition of hydroxyapatite nanoparticles as filler.

By the clinical point of view, this might be the approach to treat the longitudinal fractures of the teeth causing, in the most part of the cases, as end outcome, the extraction of the involved tooth: for this reason, the possibility of enamel and dentine laser welding seems to open interesting perspectives.

2. 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. The 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 (Fig. 2).

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 (Fig. 3).

By means of a pilot study it was noticed that the output peak power able to produce a great melting of the dental tissue with the minimal carbonization was around 30 kW at a Repetition Rate of 20 kHz and with a speed of the beam of 10 mm/sec. in focused mode.

The lens used with the AREX 20 laser has a focal length of 160 mm. In this configuration, the laser beam has a spot-size of 80 μm.

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 Peak Power and the last at 10 kW Peak Power (Average Powers of 60 and 20 W). The Repetition Rate 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, as shown in Tab. 1.

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).

Two blind specialists in histology made a qualitative evaluation of the ratio melting/carbonization in the irradiated samples, as well as of the formation of dentinal bridges between the two parts of the specimen observed.

3. Results

All the observed samples showed some 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 (Fig. 4), while speci-

Tab. 1: the three different irradiated sample groups.

<table>
<thead>
<tr>
<th>Group C (n= 8 samples)</th>
<th>Group B (n= 8 samples)</th>
<th>Group C (n= 8 samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser welding without filler</td>
<td>Laser welding with hydroxyapatite nanoparticles</td>
<td>Laser welding with hydroxyapatite powder</td>
</tr>
</tbody>
</table>

Fig. 3: 1070 nm Yb-doped pulsed fiber laser (AREX 20, Datalogic, Italy).

Fig. 4: optical microscope observation at magnification x10; a: sample of the group “a” where zones of melting and carbonization are evident with an incomplete welding process; b: sample of the group “b” where is appreciable a large amount of melting formation with a complete dentinal bridge between the two parts; c: sample of the group “c” with zone of melting, carbonization without complete welding process.
mens of groups a and c (Fig. 5-6) did not reach a complete welding process.

4. 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. 18), 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 19) 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 utilization of 1950 nm diode laser 20).

The laser welding process, as described by Wolf-de Jonge 21), 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 utilization of solders which consist of a protein or protein-like substance applied to the weld to enhance bonding.

Gerasimenko 22) proposed, for the welding of biological tissues using laser device the utilization of nano-composite solders, while Strassman 8) demonstrated the employment of the CO2 laser coupled to albumin solder in the reparative surgery of the cornea.

Semenov 23) described the tissue welding for the osseuloplasty by associating the laser irradiation to the application of platelet-rich plasma (PRP) as a solder alloy.

In 1984, Almquist et al 24) first reported the use of an argon laser in peripheral nerve repair in both rats and monkeys. The following year, Fischer et al 25) 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 26), 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.

Regard the dental hard tissues welding while there are no studies on the employment of Erbium lasers for dental hard tissues melting, the utilization of Nd:YAG and CO2 laser endodontic root apex closure is described in several papers 27, 28).

The aim of this technique was the elimination of the necessity to use any cement or resin to close the retrograde apex cavity and the studies cited showed a high success when related to the conventional treatments.

The originality and the difference of our work when related to the cited studies of Zerbinati and Neiburger is

Fig. 5: Sample of group “b”, magnification x40: optical view of the dentinal bridge between the two parts of the sample.

Fig. 6: SEM observation (magnification x35); a: sample of group “a” where it may be noticed an incomplete welding process; b: sample of group “b” with a bridge of welded tissue between the two parts; c: sample of group “c” with a large zone of melted dentine and an incomplete welding process.
the utilization, as filler, of hydroxyapatite nanoparticles. In fact, as reported in “Results”, the only way to obtain the formation of dentinal bridges was the irradiation of the nanoparticles while in the other sample groups, even with the same laser parameters, no results were observed.

The use of filling associated to CO2 laser irradiation was proposed also by Lin et al in 2000.[29] In their study, it was employed a low melting-point bioactive glass to fuse or bridge tooth fractures and, for this reason, this may be considered a brazing technique.

It is also 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.

The differences seen in the groups, all irradiated with the same parameters, may be explained by the nanoparticles present in the group b which, probably, are able to assure a great absorption of the laser energy.

A great role in the dentin welding process may be played by the pulse duration of 100ms: in fact, this very short time of irradiation, associated to pauses able to allow “relaxation times” 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, is not up today 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.

5. Conclusions

This ex vivo preliminary study, based on the dentin welding obtained by a 1070 nm 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.

References

Acknowledgments

The Authors would like to thank Datalogic S.p.A. and particularly Dr. Lorenzo Bassi for providing the fiber laser source.