Nd:YAG lasers in intraoral welding

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_Introduction

Laser welding was introduced in jewellery in the 1970s and later successfully used also by dental technicians.[1] The wavelengths that were used firstly were CO_2 and Nd:YAG, but, finally, the market was rapidly conquered by the latter because of the results that were obtained.[2] Laser welding, in fact, gives a great number of advantages in contrast to traditional welding.

First of all, the laser device saves time in the commercial laboratory because all welding is done directly on the master cast. Inaccuracies in assembly caused by transfers from the master cast and investments are reduced.[3] Furthermore, the heat source is a concentrated light beam of high power, which can minimise distortion problems on the prosthetic pieces.[4] Interesting is its possibility to weld very closely to acrylic resin or ceramic parts with no physical (cracking) or colour damage.[5] This results in saving both time and money during the restoration of broken prosthetics or orthodontic appliances because remaking to the not-metallic portions is not necessary.



Fig. 1

This welding technique may be used on every kind of metal, but its property to be very active on titanium makes it specifically qualified for prosthetics over endosseous implants.[6] Many laboratory tests demonstrated that laser welding joints have a high reproducible strength for all metals consistent with that of the substrate alloy.[7] All these advantages resulted in this procedure causing a great unrest in the technicians' laboratories and stimulated the companies to put more and more upgraded appliances on the market.

Some aspects, such as its extensive dimensions, high costs and high costs and fixed-lenses delivery system today still characterise these machines, which strictly limit their use only to technician laboratories.

The first aim of this study was to evaluate the possibility to utilise the same device normally used in dental office for laser welding. The second aim was to achieve welding directly in the mouth by employing a fibre-delivered laser after an accurate evaluation of the biological compatibility of the procedure.[8]

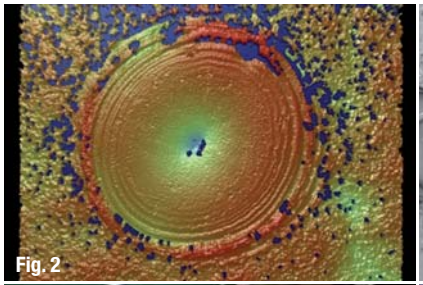


Fig. 2

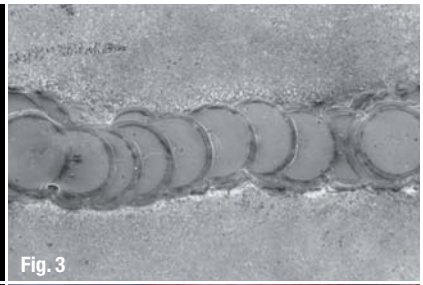


Fig. 3



Fig. 4



Fig. 5

_Material and methods

The first step of our research was to determine the wavelength most appropriate for our work among those normally used by the dentist and those applied for welding in the industrial field (CO_2—10,600 nm, Diode laser—810 nm, and Nd:YAG—1,064 nm). We made some tests on metallic plaques for each wave-





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length and we saw that the one able to weld was the Nd:YAG.

While the pulse durations of the dental CO_2 laser are too short and cannot give the thermal elevation necessary to obtain a fusion of metal, the output power of the dental diode laser is too low (from 5 to 10 Watts) and cannot give the energy necessary to support a real welding process. Therefore, we decided to use the appliance FIDELIS PLUS III (FOTONA, Slovenia, Fig. 1) which combines two different wavelengths, Er:YAG (λ = 2,940 nm) and Nd:YAG (λ = 1,064 nm).

The first wavelength allows the dentist to treat hard tissues (enamel, dentin and bone) by a mechanism which causes the explosion of intracellular water molecules by utilizing the affinity of this laser with water and hydroxyapatite, thus resulting in the ablation of the tissues.[9] The Nd:YAG laser allows the dentist to perform surgery with complete haemostasis, utilising the affinity of this wavelength with haemoglobin, therefore avoiding sutures.[10] It is also employed for the periodontal pockets and root canal decontamination, for bleaching and to treat dentinal hypersensitivity.[11]

The peculiarity of FIDELIS PLUS III is given by the possibility to have pulse durations in milliseconds (15 and 25), in addition to a pulse duration in seconds, which is necessary during dental interventions. These high pulse durations can be utilised in phlebology, in the treatment of inestethisms of vascular origin, thanks to the affinity of this wavelength for haemoglobin.[12] The optic fiber delivery system is a very important advantage of this device with regard to intraoral welding, because it is very flexible and ergonomic and therefore able to penetrate into the oral cavity.


Fig. 6


Fig. 7


Fig. 8


Fig. 9

We decided to use a fiber of 900 µm in diameter, normally used for bleaching and biostimulation. Initially, a handpiece with a 2 mm spot (Fotona R 30), normally used in dermatology, was chosen and, by reducing the working distance, a spot of 1 mm was obtained. We asked the manufacturer to construct an experimental hand piece capable of generating a 0.6 mm spot. The aim was to increase fluence (J/cm^2), which is the most important parameter determining the quantity of energy delivered to a surface, by a factor of 10, while also utilising the device's maximum energy output (9.90 J).

_"*In vitro*" tests

The first *in vitro* test was conducted by irradiating CrCoMo plates with various combinations of welding parameters. The spot's configuration was analysed by an interferometric technique. Interferometry is a non-contact, optical technique for measuring surface height and shape with great speed and accuracy. Interferometry makes it possible to precisely measure the shape and size of the laser's crater in the metal surface in three dimensions, and allowed us to choose laser parameters that welded well, but minimised collateral damage to the surrounding area (Fig. 2). In these preliminary tests, the best parameters found were: output power = 9.90 W, frequency = 1 Hz, pulse duration= 15 ms, working distance = 30 mm, energy = 9.90 J, fluence = 3,300 J/cm^2.

The subsequent tests were performed on CrCoMo plates and steel orthodontic wires to compare the welding by dental laser (Fidelis, Fotona) to this obtained by the use of a device normally utilised in dental laboratories (Rofin, Germany).[14] In addition, metal fillers were used. Different techniques (Fig. 3) were employed to analyse the results: SEM (Scanning Electron Microscope), EDS (Energy Dispersive Spectroscopy) and DMA (Dynamic Mechanical Analysis). The results of the two sample groups were similar with regard to microstructure, elemental distribution on the welding fillets, strength off the joints and elastic modules.

In order to obtain a device able to weld every kind of metal and alloy, including titanium, we added an argon gas cylinder connected to a pipe to the appliance, spreading the gas to the laser impact beam by means of an additional pedal. The titanium samples welded under this shielding atmosphere did not show any trace of oxidation.

_"*Ex vivo*" tests

In order to define the thermal increase in the biological structures close to the zones which are thermally affected by the welding process (sulcus, pulp

chamber, bone and root), an *ex vivo* study was performed.[15,16]

Two fresh calf jaws were kept at room temperature and holes were made in the disto-labial area in six molars of each jaw by micro motor drill. Then, four k-type thermocouples were connected to each tooth and fixed with thermoplastic paste (Impression Compound Red Sticks, Kerr) in the pulp chamber, sulcus, bone and root.

The thermocouples were then connected to a PC-integrated four-channel thermometer (LUTRON TM-946) in order to record and save the data. Twenty-four metallic CrCoMo plaques were curved to hemispherical shape (15 mm ray) and a couple of them were placed on every previously prepared tooth. Since the first examination was performed by an IR thermal camera, limited in that it only provides the surface evaluation of the jaw, it was decided to use the four-thermocouples system which, although its application is more difficult and will take longer, allows checking the internal temperature of the structures. A rise in temperature was recorded in the pulp chamber. However, for all the twelve samples tested, the maximum temperature rise was lower than 5.5 °C, which is considered a critical value for pulp vitality.

A similar test was then performed on pork jaws by welding a titanium bar to implants previously inserted into the bone under argon gas atmosphere (Fig. 4). The values recorded by thermocouples placed closely to the implants showed a thermal elevation much lower than those considered dangerous for bone necrosis (5 to 7° = protein coagulation). After these *in vitro* and *ex vivo* experiments, it was decided to apply this technique to *in vivo* clinical situations.

_Clinical cases

Case 1

A 59-year-old male patient presented with implant-prosthetic treatment which consisted in the apposition of a fixed prosthetics placed in to the upper arch with two crowns and five endosseous implants (Fig. 5). After crown preparation and impression taking, the dental technician constructed the metallic structure of the bridge in two sections to assure its fit and, to avoid the risk of inaccuracies in the impression, it was decided to connect them by intraoral laser welding.

In order to protect the soft tissues from the ejection of warm metal splinters, we utilised the silicon mass normally used to take prosthetic impressions with a little hole corresponding to the contact of the two portions of prosthesis (Fig. 6). The entire process had a duration of seven minutes, the effective welding time was 150 seconds, the parameters used were the same as described before and it was utilised a filler metal. After removing the bridge from the mouth, it was sent to the laboratory to complete its realisation (Fig. 7). During and after the welding process, the patient said the he did not felt any discomfort. After four weeks we could seal the bridge and finish the rehabilitation of the patient (Fig. 8).


Fig. 10


Fig. 11


Fig. 12


Fig. 13

Case 2

A 14-year-old female patient, in orthodontic treatment with a fixed appliance (modified "VELTRI" distaliser) for the insertion of the first premolars into the upper arch, came to our clinics for a check and we noticed that an arm of the appliance was broken (Fig. 9). We evaluated that the removal of the appliance was full of risks, in particular the impossibility to reinsert it after the repairing due to space closure. Therefore, it was decided to laser-weld the arm intraorally. In order to protect the soft tissues from the ejection


Fig. 14


Fig. 15


Fig. 16


Fig. 17


Fig. 18


Fig. 19


Fig. 20


Fig. 21

of metal pieces during irradiation, we used a silicon sheet (Fig. 10). After repairing the arm (Fig. 11), the appliance was reactivated by turning the screw, until the space required to insert the premolar was reached (Fig. 12). During the laser welding process, which had a total duration of 2 min and a time of irradiation of 20 sec, the patient didn't feel pain or discomfort and the vitality of the teeth and the periodontal and gingival health was not damaged, even months and years later.

Case 3

A 45-year-old male patient came to our office for a fixed prosthetic rehabilitation of the lower arch. In the upper arch, he had a gold-resin fixed prosthesis which was broken in the middle, between the two central incisors (Fig. 13). Therefore, we decided to use the intraoral laser-welding technique to repair the bridge intraorally. We removed a little portion of resin by the two incisors with a bur and welded by Fidelis III with a metal apposition. In this case, the protection of soft tissues was achieved by a plastic cylinder (Fig. 14). After welding, we put a layer of composite resin to complete the restoration aesthetically (Fig. 15). During the welding process, which had a duration of seven minutes with an irradiation time of 130 seconds, the patient did not felt any discomfort. Subsequent checks, made after one month, two, six, twelve and eighteen months, evidenced no problems.

Case 4

A 67-year-old male came to our clinic for an examination. At the clinical observation, the man appeared edentulous on the upper arch where he wore removable full dentures. His problem was that the device was not stable and he had a great discomfort in speaking and eating. Due to his economic condition, it was decided to stabilise his appliance by the insertion of four implants in the maxillary bone. The medical history did not reveal any aspects of concern and the patient confirmed he did not take any kind of medication.

An impression of the upper arch was taken in order to construct a template for correctly positioning the implants. The insertion of the four implants 4.5 × 11 mm (AoN, Vicenza, Italy) was performed flapless and with the aid of the template (Fig. 16). After the surgical procedure, four abutments were screwed to the implants. Then, a bar previously constructed by the dental technician previewing the position of the implants by the maxillary arch impression was inserted in the four abutments (Fig. 17). The bar was welded intraorally by dental Nd:YAG laser in order to fix the position. The whole intraoral welding procedure had a duration of 47 sec, during which the patient confirmed he did not experience any pain or discomfort (Fig. 18).

The bar was removed from the mouth with the abutments and the welding procedure was completed extraorally with the device previously used (Fig. 19). The abutments were cut and polished, and then they were reapplied to the mouth (Fig. 20). The prosthesis was then connected to the bar with four silicon OT Cap (Rhein 83, Italy), fixed by acrylic (Fig. 21). The patient was checked after two, seven, and fifteen days, then monthly for six months. During this period, no problems were reported by the patient who has thus regained his comfort.

_Conclusion

Intraoral Laser welding (ILW), even if it is only at its beginning, is a procedure which is both promising and relevant for the restoration of a damaged prosthesis. It can be done without the risks related to prosthesis removal as well as during prosthesis construction in order to eliminate the accuracies related to the impression. The most interesting application of this technique regards the possibility to weld a bar on endosseous implants intraorally in order to immediately charge them. Further studies will find other applications for this new approach._

_contact laser

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