Laser welding and syncrystallization techniques comparison: “Ex vivo” study

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Background and aims: Stabilization of implant abutments through electric impulses at high voltage for a very short time (electrowelding) was developed in the Eighties.

In 2009, the same procedure was performed through the use of laser (laser welding)

The aim of this study is to compare electrowelding and laser welding for intra-oral implant abutments stabilization on “ex vivo models” (pig jaws).

Materials and methods: Six bars were welded with two different devices (Nd:YAG laser and Electrowelder) to eighteen titanium implant abutment inserted in three pig jaws. During the welding process, thermal increase was recorded, through the use of k-thermocouples, in the bone close to the implants.

The strength of the welded joints was evaluated by a traction test after the removal of the implants. For temperature measurements a descriptive analysis and for traction test “values unpaired t test with Welch’s correction” were performed: the significance level was set at $P < 0.05$.

Results: Laser welding gives a lower thermal increase than Electrowelding at the bone close to implants (Mean: 1.97 and 5.27); the strength of laser welded joints was higher than that of Electrowelding even if not statistically significant. (Mean: 184.75 and 168.29)

Conclusion: Electrowelding seems to have no advantages, in term of thermal elevation and strength, while laser welding may be employed to connect titanium implants for immediate load without risks of thermal damage at surrounding tissues.

Key words: Nd: YAG laser • welding • syncrystallization • implants

Introduction

Implantology has had a great evolution in the last years: in fact, even if most authors demonstrated that the process of osseointegration and the subsequent implant load needs at least three months to take place in the lower jaw and six in the maxilla ¹⁾, a great interest developed about the immediate loading technique.

Donath et al ²⁾ reported that the load applied on the implant surface may interfere with the bone formation and it also may lead to fibrous encapsulation. However, several clinical and experimental studies

showed that long-term success of removable and fixed prostheses is possible also on immediately loaded implants. ^{3,4)}

A clinical study based on a consistent number of implants showed the predictability and the high success percentage in immediately loaded cases ⁵⁾ and the same authors demonstrated the absence of statistical differences, in term of osseointegration and success percentage, between immediately and subsequently loaded implants, with a follow-up of 7 years ⁶⁾. The key factor connected to the success of the immediately loaded implants seems to be related to the absence of movement of 100 μm or more just after their placement ^{7,8)}. Other studies indicated a micro-movement of 150 μm acceptable for a complete integration ^{9,10)}. Therefore, the possibility to immediately splint the

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implant abutments after implant placement generated a very great interest ¹¹⁾.

At the moment only two techniques have been described as able to weld metals intra-orally, the Electrowelding and the Nd:YAG laser welding.

The Electrowelding, firstly described by Mondani in 1982, consists in the creation of an electric arch between two electrodes under an argon gas flux, based on the physic process of "syncrystallization". On the basis of the high temperature generated on the welding surface for the very short time of two thousands of second, syncrystallization works by binding all those materials, such titanium, surgical steel and non-noble metal alloys, which are poor conductors of electricity. ¹⁴⁾

The laser welding technique in dentistry was firstly described by Gordon in 1967 and it has been used since the 1970's in dental laboratories, demonstrating its advantages over traditional welding methods. In the last years, several works described the possibility to weld metals with the same Nd:YAG device used in dental office for oral surgery ¹⁵⁾, endodontics ¹⁶⁾, periodontics ¹⁷⁾ and bleaching ¹⁸⁾.

Thanks to its delivery system consisting in optical fiber, it has been proposed also for the Intraoral Welding, supported by "in vitro" and "ex vivo" studies in which the quality of the joint and the moderate thermal elevation in the zones close to the welded joint have been evaluated ¹⁹⁻²¹⁾.

Some papers reported several cases where intra-oral laser welding (ILW) technique was used in prosthodontics, orthodontics and implantology ^{22,23)}.

The aim of the present study was to compare the

thermal increase and the strength of laser welding and electrowelding by "ex vivo" test with a "split mouth" model.

For the purposes of this study the null hypothesis assumed that thermal increase and strength in the welded zone don't present any differences, whatever the technique utilised.

Material and methods

Three pig jaws freshly sacrificed were kept at room temperature and, on the two sides of each of them, three implants of 10 mm length and 5 mm in diameter (Easydip Implants, Overmed srl, Milano, Italy) were inserted into the alveolar bone, in the anterior-lateral zone (canine and premolars) at an approximate distance of 20 mm between each of them. Implant sites were prepared through the use of a surgical micro-motor (Implantmed, W&H Italia, Bergamo, Italy) under continuous physiological solution (Sodio Cloruro 0.9%, Eurospital, spa, Milano, Italy) irrigation. **(Fig. 1)**

Subsequently, a hole was performed in the vestibular bone at 5 mm from the alveolar crest, till the encounter with the implant surface to insert a k thermocouple (CNXt3000, Fluke Europe bv, Amsterdam, Netherlands). A probe was inserted into each hole and an X-ray was performed in order to check the position of the k thermocouple. **(Fig. 2)**

A titanium abutment (Overmed srl, Milano, Italy) was connected to each implant and a 3 Grade (ASTM International classification) titanium bar (Panthera Dental, Québec, Canada) of 2 mm diameter was welded to the abutments of each jaw, in one side (for a

Fig. 1: Pig jaw with six implants inserted

Fig. 2: X-ray with the thermocouples inserted

total of 6 bars) through the use of an electrowelder (VISION STRATEGICA Newmed srl, Reggio Emilia, Italy (**Fig. 3**) and in the other side by laser device (Fidelis III Plus, Fotona, Ljubljana, Slovenia). (**Fig. 4**) During all the welding procedure the bone thermal elevation was recorded by the k thermocouple

Due to the necessity to weld titanium under shield atmosphere, Argon gas was spread, during all the procedures,; its utilization, without risks also “*in vivo*” in human subjects, has been reported by several authors ^{24,25)}

The electrowelder and the Nd:YAG laser device were used with the following parameters respectively: 25V, 50 Hz, 312J and output power 9.85W, frequency 1Hz, energy 9.85J, pulse duration 15 msec.

The spot beam obtained with a working distance of 40 mm had a diameter of 0.6 mm, and the fluence was 3300 J/cm². All the welding procedures were per-

formed without filler metal.

Implants were extracted from the jaws by clamping each of them with a narrow plier without touching the bar and the quality of the strength joint was evaluated by traction tests

Each implant was clamped to a wise and the point of connection of the bar to the implant was connected to a dynamometer (SBS-KW-300A, Steinberg, Berlin, Germany) mounted on a manual stand in order to record the force (in N) necessary to detach the bar from the abutment. (**Fig. 5-6**)

The difference of temperature between the start and the end of the welding process was recorded.

For temperature measurements a descriptive analysis and for traction test “values unpaired t test with Welch’s correction” were performed; the significance level was set at $P < 0.05$.

Fig. 3: Syncrystallization process

Fig. 4: Laser welding process

Fig. 5: Traction test on the bar

Fig. 6: Detach of the bar from the implants

Results

On each sample, the electrowelder gave the highest values of thermal elevation. (Table 1-2)

The traction test on the two groups showed higher values on the samples welded by laser device, even if no statistical significance was observed. (P<0.05.) (Table 3-4)

Discussion

Currently, only two techniques potentially useful to weld metals intra-orally have been described: the Electrowelding and the Nd:YAG laser welding and a comparative analysis among these two techniques can be difficult mainly on the base of the great physical differences.

Laser technology is the most efficient method for delivering thermal energy to small areas and, according to many Authors ^{26,27}, it is one of the best fusion welding techniques for different metals. This depends on the possibility, to focus the light beam in a focal point. Such a beam delivers energy into the metal

causing an increase of temperature which is able to liquefy the material metal-heat. The metal evaporates and a cavity is formed immediately under the heat source and a reservoir of melted metal is produced around it. As the heat source moves forward, the hole is filled with the melted metal from the reservoir and this solidifies to form the weld bead ²⁸.

The best advantage is that the weld process can usually be performed exactly where it is required, i.e. at the level of an implant abutment.

Moreover, the procedure can be carried out directly on the master cast thereby eliminating the risk of inaccuracies and distortions due to the duplication of the model ²⁹. Moreover, the heat source is a concentrated high-power light beam, minimizing distortion problems in the prosthetic pieces ³⁰. The process allows the possibility of welding in proximity to acrylic resins or ceramic parts with no physical (cracking) or colour damage ³¹. These characteristics are associated to a shortening of working time by eliminating the necessity for remaking of broken prosthetic or orthodontic appliances. Laboratory tests have shown that laser-welded joints have a high, reproducible strength ³².

Table 1: Mean (SD) temperatures of each K thermocouple at beginning and end of the welding process in two groups.

Thermocouples	Laser			Electrowelder		
	T1	T2	T3	T1	T2	T3
Initial temperature (°C)	25.5	27.2	25.2	26.6	26.4	24.5
Final temperature (°C)	25.6	27.4	25.2	31.6	27	35.8
Differential temperature (°C)	0.1	0.2	0	5	0.6	11.1
Mean differential temperature (°C)		0.10			5.56	
Standard deviation		0.10			5.27	

Table 3: Mean (SD) of the strength values of the two groups.

	Group A	Group B
Col. title	Laser	Electrowelder
Mean	184.75	168.29
Standard deviation (SD)	91.600	72.260
Sample size (N)	12	12
Std. error of mean (SEM)	26.443	20.860
Lower 95% conf. limit	126.55	122.38
Upper 95% conf. limit	242.95	214.20

Table 2: Comparison of the two devices temperature variations

Table 4: Traction Test: comparison between the two groups

In order to stabilize implant abutments “in vivo”, Mondani and Hruska proposed, in the 80's, a welding machine which works through the current impulse at very high voltage, for a very short time, thus allowing the inter-digitations of the titanium prisms, resulting in a welding through a process called “syncrystallization”^{33,34}.

In physics, the “syncrystallization” is the union of two metal surfaces by sharing the atoms when building the crystal lattice in the junction zone while “electric resistance welding” is an autogenic welding procedure through the employment of pressure, where the heat necessary to reach the melting or forging temperatures is supplied by an electric arch³⁵.

In the welding cycle three phases are identified: 1) the joining where pressure alone with no current is applied; 2) the welding with the simultaneous actions of pressure and current and 3) the cooling where the current is cut off and the pressure only is kept³⁸.

In literature there are not studies about the thermal increase close to the implants during the welding process, whatever the technique used. Such an aspect should be considered as a key factor, considering the great role of the temperature in the long-term success of the implant-prosthetics therapy.

Unlike industrial solders that can operate only in the presence of argon and without oxygen in the atmosphere, the Electrowelder used in dentistry can work in presence of oxygen, water, physiological oral fluids and blood³⁶.

The limits of this technique are the impossibility to weld all kind of metals and alloys, the impossibility to be used on patients with pacemakers, and the possible damage to the surrounding structures (teeth, acrylic, ceramic etc)³⁷.

The Intraoral Laser Welding (ILW) technique is effective on all metals and alloys and it can be applied either with or without filler metal and shielding gas; because of the small spot size of the beam (0.6 mm), it is able to restrict the high temperature within a very limited area.

In a previous work, Authors demonstrated by an “in vitro” study on plates positioned over the teeth in bovine jaws that, during the laser welding process, the temperature at the surrounding structures level, i.e. pulp chamber, is very low and biologically harmless²¹ and this works may be considered as a completion and integration of the investigation.

Regarding electrowelding, even if many clinical cases are described in several works^{38,39,40} the paucity of “in vitro” studies about the physical mechanisms and thermal elevations in the biological tissues makes

still very difficult to make a clear point of view on this procedure. , this representing an important limit because the possibility to cause an overheating in the tissues represents a real risk in these kinds of situation. For this reason, the importance of this “ex vivo” consists in the analysis of the biological possible damages by using this technique, results demonstrating that it is not free of risks.

Experimental studies determined that, approximately, 15–20% of the osteoblasts become necrotic after being exposed to 48°C for 10 minutes, while they withstood 45°C without damage⁴¹. After heating the superficial skull of rats to 48°C for 15 minutes, areas with dead osteocytes were found, and the formation of new bone was delayed⁴². From the available literature on bone reactions to increases in temperature during drilling and sawing, it was concluded that 47°C is a critical temperature⁴³.

This is also considered, in literature, the limit to not exceed in order to achieve the complete bone integration of the implants and to guarantee the complete long-term success of the implant-prosthetic treatment⁴⁴⁻⁴⁶.

Regarding the quality of the welded joint, these tests evidenced the same results of the literature. In fact, a previous “in vitro” study¹² made on CrCoMo plates showed that the quality of the electrowelding, by the point of view of the strength, is lower than the laser welding, giving this an important indication to the clinic.

Conclusion

This “ex vivo” study, even if with some limits consisting in the low number of samples, showed that the laser welding process seems to give a modest thermal elevation in the bone close to the implants, by far lower than the values, as above described, considered dangerous for their integration and the long-term success of the prosthetic rehabilitation.

If compared to the Electrowelding, this may be considered another great advantage of Nd:YAG laser welding, in addition to the others before described.

Moreover, also the physical characteristics such as the strength in the joints, presented result which may give a great importance to the technique in the field of implant-prosthetics rehabilitations.

Laser welding may be used also intra-orally to connect titanium implant abutments within the technique of the immediate load, without the risk of thermal increase into the bone and with good results in term of mechanical strength, while the syncrystallization

demonstrated to have, beyond the limits above described such the possibility to weld only with an overlapping of the two portions, only few kinds of metal and alloy and only without filler, no advantages

in term of thermal elevation and strength.

Further studies will be necessary to confirm these results.

References

- 1: Davies JE. (1998): Mechanisms of endosseous integration. *Int J Prosthodont.*, 11(5):391-401
- 2: Donath K, Laass M, Günzl HJ. (1992): The histopathology of different foreign-body reactions in oral soft tissue and bone tissue. *Virchows Arch A Pathol Anat Histopathol.* 420(2):131-7
- 3: Ledermann PD. (1988): New Ledermann screw. *Quintessenz.*, 39(5):799-815
- 4: Degidi M, Piattelli A, Felice P, Carinci F. (2005): Immediate functional loading of edentulous maxilla: a 5-year retrospective study of 388 titanium implants. *J Periodontol.*;76 (6):1016-24
- 5: Degidi M, Piattelli A. (2005): Comparative analysis study of 702 dental implants subjected to immediate functional loading and immediate nonfunctional loading to traditional healing periods with a follow-up of up to 24 months. *Int J Oral Maxillofac Implants.*, 20(1):99-107. Erratum in: *Int J Oral Maxillofac Implants.* 2005; 20(2):306.
- 6: Degidi M, Piattelli A. (2005): 7-year follow-up of 93 immediately loaded titanium dental implants. *J Oral Implantol.*, 31(1):25-31
- 7: Brunski JB, Moccia AF Jr, Pollack SR, Korostoff E, Trachtenberg DI. (1979): The influence of functional use of endosseous dental implants on the tissue-implant interface. I. Histological aspects. *J Dent Res.*; 58(10):1953-69
- 8: Brunski JB. (1993): Avoid pitfalls of overloading and micromotion of intraosseous implants. *Dent Implantol Update*, 4(10):77-81
- 9: Cameron H, Macnab I, Pilliar R. (1972): Porous surfaced Vitallium staples. *S Afr J Surg.*;10(2):63-70
- 10: Pilliar RM, Lee JM, Maniopoulos C. (1986): Observations on the effect of movement on bone ingrowth into porous-surfaced implants. *Clin Orthop Relat Res*, (208):108-13
- 11: Melilli D, Rallo A, Cassaro A. (2011): Implant overdentures: recommendations and analysis of the clinical benefits. *Minerva Stomatol.* 60(5):251-69. Review. English, Italian.
- 12: Fornaini C, Merigo E, Vescovi P, Meleti M, Nammour S (2012): Laser welding and syncrization techniques comparison: in vitro study. *Int J Dent.* 21
- 13: Leretter M, Sinescu C, Negrutiu M, Negru R, Faur N, Hluscu M et al (2007I) : Intraoral welding of implants abutments with a prefabricated titanium bar. *Europ Cells and Mater* : 14(3)
- 14: Vannini F, Nardone M (2004): Emerging transmucosal single-stage implants with electro-welding and immediate loading. *Annali di Stomatologia*; LIII(3):129-135
- 15: Fornaini C, Rocca JP, Bertrand MF, Merigo E, Nammour S, Vescovi P. (2007): Nd:YAG and diode laser in the surgical management of soft tissues related to orthodontic treatment. *Photomed Laser Surg.* 25(5):381-92.
- 16: Hasheminia SM, Birang R, Feizianfard M, Nasouri M (2012): A Comparative Study of the Removal of Smear Layer by Two Endodontic Irrigants and Nd:YAG Laser: A Scanning Electron Microscopic Study. *ISRN Dent.*; Jul 16.
- 17: Eltas A, Orbak R. (2012): Clinical effects of Nd:YAG laser applications during nonsurgical periodontal treatment in smoking and nonsmoking patients with chronic periodontitis. *Photomed Laser Surg*, 30(7):360-6.
- 18: Strobl A, Gutknecht N, Franzen R, Hilgers RD, Lampert F, Meister J. (2010): Laser-assisted in-office bleaching using a neodymium:yttrium-aluminum-garnet laser: an in vivo study. *Lasers Med Sci.* 25(4):503-9
- 19: Fornaini C, Bertrand C., Bonanini M, Rocca J, Nammour S. (2009): Welding in the dental office by fiber-delivered laser: a new technique. *Photomed Laser Surg*;27(3):417-23
- 20: Fornaini C, Passaretti F, Villa E, Rocca JP, Merigo E, Vescovi P *et al* (2011): Laser welding: ultrastructural and mechanical analysis to compare laboratory laser and dental laser. *Lasers Med Sci.*, 26(4):415-20
- 21: Fornaini C, Bertrand C, Rocca JP *et al.* (2010): Intraoral Laser Welding: An in vitro evaluation of thermal increase. *Lasers Med Sci*, 25(4):473-7
- 22: Fornaini C, Vescovi P, Merigo E, Rocca JP, Mahler P, Bertrand C *et al.* (2010): Intraoral metal laser welding: a case report. *Lasers Med Sci*, 25(2):303-7
- 23: Fornaini C, Merigo E, Cernavin I, Lòpez de Castro

- G, Vescovi P. (2012): Intraoral Laser Welding (ILW) in Implant Prosthetic Dentistry: Case Report. Case Rep Dent.; 2012: 839141
- 24: Degidi M, Nardi D, Piattelli A. (2008): Immediate loading of the edentulous maxilla with a final restoration supported by an intraoral welded titanium bar: a case series of 20 consecutive cases. J Periodont; 79:2207-13
- 25: Avvanzo P, Fabrocini LA, Ciavarella D, Avvanzo A, Lo Muzio L, and De Maio RA (2012) Use of Intraoral Welding to Stabilize Dental Implants in Augmented Sites for Immediate Provisionalization: A Case Report. Journal of Oral Implantology: 38, (1), 33-41.
- 26: Dawes C. Laser Welding. Cambridge (England): Abington Publishing Ltd, 1992
- 27: Ream SL. Laser materials processing. New York: Springer-Verlag, 1988
- 28: Baba N, Watanabe I, Liu J, Atsuta M. (2004): Mechanical strength of laser-welded cobalt-chromium alloy. J Biomed Mater Res B Appl Biomater. 15; 69(2):121-4
- 29: Fusayama T, Wakumoto S, Hosoda H. (1964): Accuracy of fixed partial dentures made by various soldering techniques and one-piece casting. J Prosth Dent, 14, 334-342
- 30: Van Benthem H. (1991): Advantages of laser welding compared to conventional joining. Quintessenz Der Zahntechnik, 17:1178-1193
- 31: Bertrand C, Le Petitcorps Y, Albingre L, Dupuis V (2001): The laser welding technique applied to the nonprecious dental alloys: procedure and results. Br Dent J, 190(5): 255-7
- 32: Dobberstein H, Orlick H, Zuhrt R. (1990): The welding of cobalt-chromium, nickel-chromium and silver-palladium alloys using a solid state laser. Zahn Mund, Und Kieferheilkunde Mit Zentralblatt, 78,: 259-61
- 33: Mondani PL, Mondani PM. (1982): The Pierluigi Mondani intraoral electric solder. Principles of development and explanation of the solder using syncrystallization Riv. Odontostomatol Implantoprosesi.; 4
- 34: Hruska AR. (1987): Intraoral welding of pure titanium. Quintessence Int. 18(10):683-8
- 35: Grotowski T. (2007): Syncrystallization-technique for joining dental implants. Physical and clinical observation in 17-year old. Mgazyin Stomatologiczny (Polony);6: 58-69
- 36: Fanali S, Perrotti V, Riccardi L, Piattelli A, Piccirilli M, Ricci L *et al.* (2010): Inflammatory infiltrate, microvessel density, vascular endothelial growth factor, nitric oxide synthase, and proliferative activity in soft tissues below intraorally welded titanium bars. J Periodontol. 81(5):748-57.
- 37: Fanali S, Villa T, Fanali D and Carinci F. (2011): Optimization of implant-abutment connection in electro-welded implantology: study and mechanical characterization. European Journal of Inflammation, 9(1) (S):63-70.
- 38: Degidi M, Daprile G, Piattelli A. (2012): Implants inserted with low insertion torque values for intraoral welded full-arch prosthesis: 1-year follow-up. Clin Implant Dent Relat Res.;14 Suppl 1:39-45
- 39: Gehrke P. (2006): The syncrystallization technique: expediting rigid splinting of immediately loaded implants. Dent Implantol Update. ;17(3):17-23
- 40: Tramonte S Umberto, A, Dominici D, and Gregori M. (2011): Immediate Loading with Intraoral Welding for Improved Implant Stability during Healing. International Journal of Oral Implantology and Clinical Research 2.2 85-91.
- 41: Li S, Chien S, Branemark PI. (1999): Heat shock-induced necrosis and apoptosis in osteoblasts. J Orthop Res.; 17: 891-899
- 42: Yoshida K, Uoshima K, Oda K, Maeda T. (2009): Influence of heat stress to matrix on bone formation. Clin Oral Implants Res; 20:782-790
- 43: Gronkiewicz K, Majewski P, Wisniewska G, Pihut M, Loster BW, *et al.* (2009): Experimental research on the possibilities of maintaining thermal conditions within the limits of the physiological conditions during intraoral preparation of dental implants. J Physiol Pharmacol, 60Suppl 8:123-127
- 44: Tehemar SH. (1999): Factors affecting heat generation during implant site preparation: a review of biologic observations and future considerations. Int J OralMaxillofac Implants, 14(1):127-36
- 45: Abouzgia MB, James DF. (1997): Temperature rise during drilling through bone. Int J Oral Maxillofac Implants.;12(3):342-53
- 46: Cordioli G, Majzoub Z. (1997): Heat generation during implant site preparation: an in vitro study. Int J Oral Maxillofac Implants.;12(2):186-93