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Intraoral welding of titanium dental implants: Characterization of the joints

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ABSTRACT

The aim of this work is to find the optimal conditions to obtain a continuous joint without alterations/oxidations in the intraoral welding of titanium by electric resistance technique. The proposed technique allows intraoral welding of titanium in order to obtain the solidarization of dental implants for improving their primary stability. Commercially pure titanium (c.p. Ti) wires and dental screws were welded by electric resistance technique. A metallographic and mechanical evaluation of the joining area was performed by electronic and optical microscopy, as well as by hardness measurements. The welding has been realized in different conditions by a circumferential pulse welding machine, in order to investigate the eventual drawbacks and to optimise the welding procedure. Moreover, the attention was focused on the use of a flux of argon during the procedure, in order to avoid oxidation and to improve the microstructural characteristics of the joint. The characterization of various welded Ti wires led to the individuation of the optimal conditions to obtain a continuous joint without alterations or oxidations. The best results were obtained by using two impulses and argon flux. A clinical case demonstrates the effectiveness of the technique in the improvement of dental implants primary stability.

1. Introduction

Titanium and its alloys are the metals of choice in biomedical applications due to their high biocompatibility, low density, good mechanical properties and corrosion resistance.

With the introduction of titanium by Tramonte in the early 1960s, it has been shown to implantologists the advantages of a material that, in addition to biocompatibility, allowed the opportunity to be welded and mechanically coupled in the mouth as reported by Hruska (1987). Due to the high diffusion of titanium based materials in dentistry, their weldability is a topic of interest in this field (e.g. orthodontic wires) as discussed by Matsunaga et al. (2015) for laser and electrical welding of various titanium-based wires, Iijima et al. (2008) for electrical resistance of β-titanium wires, Akman et al. (2009) for laser welding of Ti6Al4 V alloy and also by Wang and Welsch (1995) for tungsten inert gas and laser welding and infrared brazing of titanium. Weldability of commercially pure titanium (c.p. Ti) is in general very good. The main problems in the welding of titanium based materials are the formation of a heat affected zone and the high reactivity of titanium with oxygen, nitrogen and hydrogen at high temperatures as reported by Matsunaga et al. (2015) for laser and electrical welding of various titanium-based wires, Iijima et al. (2008) for electrical resistance of β-titanium wires, Akman et al. (2009) for laser welding of Ti6Al4 V alloy and also by Wang and Welsch (1995) for tungsten inert gas and laser welding and infrared brazing of titanium. Contamination of the weld metal and adjacent zone will increase tensile strength and hardness, but they reduce ductility to an unacceptably low value, such that cracks may occur even in conditions of only moderate restraint. The most likely contaminants are oxygen and nitrogen, picked up from the air, and hydrogen deriving from moisture or surface contamination. Li et al. (2005) suggested the maximum tolerable limits in weld metal as 0.3% oxygen, 0.15% nitrogen and 150 ppm hydrogen. Scrupulous cleanliness is essential for both parent metals, but in the case of intraoral welding, the use of medical grade and sterilized materials significantly reduces any inconvenience coming out from surface contaminants. Moreover, protective shielding with inert gases can be added as protection against oxidation, but Akman et al., 2009 underlined that it can lead to porosity in the final joint due to gas bubble entrapment, and its efficacy must be verified. The here proposed electric resistance

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welding is accomplished without filler metal, therefore, biocompatibility and corrosion resistance of the base metal can be retained. Mondani presented the first intraoral welder at the beginning of the 1980s (Mondani and Mondani, 1982) and it was based on electric resistance welding. The welding by electric resistance is a process in which the needed heat is locally provided by the electrical resistance of the material, under the flow of a high density current. Further studies allowed the author to design and patent, nationally (Lorenzon 0001396770, 2012a) and internationally (Lorenzon US 7 390 988 B2, 2008) a circumferential pulse welding machine. Kahraman (2007) indicated that,. for industrial application, Ti and its alloys are generally welded to each other by laser beam, electron beam and gas tungsten arc welding., Some others welding techniques, such as laser or plasma welding have been proposed for specific dental applications, as indicated by (Roggensack et al., 1993), but it is reported that they induce the presence of a heat affected zone, reducing the durability of the joints; it is larger in the case of plasma welding. Resistance welding is a useful method because it allows avoiding the presence of a heat affected zone (as here reported) and over-heating of the surrounding soft tissues. Moreover, Sundaresan et al. (1999) reported that the microstructure can be refined, by using quite short time of heating, without adversely affecting the intragranular microstructure. The technique described in the present paper is innovative because it allows the intraoral welding of titanium bars and dental screws in order to solidarize implants for an improvement of their primary stability with a peculiar process.

The main purpose of the joining of implants to a bar is to increase their primary stability, in order to finally promote the integration of implants with bone. Several screws implanted at the same time in the mouth, mechanically become a whole implant, because of the presence of the joined bar, which is able to distribute loads and stresses. Lorenzon (2012b) highlighted that joined implants structurally represent a completely different system from the individual unconnected implants. The most important element in mechanical coupling of the implants is the lack of the typical *peri*-cervical resorption. It is a direct consequence of the distribution of stresses on the intra-cortical cross section. As first, the welded bar improves the primary stability of post-operative retaining and then it transforms the structural system from simple to complex. The complex system (joined implants) can be described as a beam on several pillars, while the simple one (un-joined implants) consists of individual pillars. Lorenzon and Bignardi (2003) and Pierazzini (1979) evidenced that the biomechanical behaviour of the complex system is completely different, following well known laws of mechanics. The joining by an electro-welded bar leads to a long survival of complex prosthetic implants. The author has, in his clinical experience, several cases of implants surgically inserted since more than 25 years ago which are fully functional at the present time (Lorenzon 2007; http://www.centrochirurgicosrl.it/en/functional-implantology-dental-implants-clinical-cases/).

The author (Lorenzon 2007) clinically observed that if the bar is removed bone resorption occurs. This is not a harmless phenomenon, but it is a progressive alteration going on with the deepening of the lesion.

In this research work, a comparison between different welding conditions (one or two electric impulses, optional argon employment) has been carried out on some model junctions, realized between two titanium wires with an innovative welding resistance apparatus developed and patented by the author nationally (Lorenzon 0001396770, 2012a) and internationally (Lorenzon US 7 390 988 B2, 2008). The characterization has been performed by means of electronic and optical microscopy and hardness analyses. Moreover, an optimized junction between titanium wires of different diameters and titanium dental implants have been analysed. The best joint does not show the typical zone of oxidation associated with a heat affected interface described by (Hruska and Borelli, 1991). The creation of an un-oxidised circumferential ring is of relevance because it can result in protection from stress corrosion, due, for instance, to bacterial corrosion. Moreover, the structural integrity of the elements (implants and bar) is maintained, because of the absence of surface oxides. The band of thermally altered material, often observed on titanium after welding, is absent by using this technique.

2. Materials and methods

2.1. Samples preparation

The implants employed, as a model for this analysis, were commercial products manufactured by Functional Devices (FD t/s type). Titanium wires were made of commercially pure titanium (c.p. Ti) grade 2 (TITANMED) and cleaned by washing in water and alcohol before welding.

The equipment used for welding was a circumferential pulsing machine, it was designed by the author in order to avoid structural weakness of the intraoral joints (Lorenzon US 7 390 988 B2, 2008) and (Lorenzon 0001396770, 2012a). It is manufactured by Sintermedica (Sinter-1). The application of the electrodes to the elements to be welded was made by applying a pre-set pressure. The applied pressure allows a defined plastic deformation of the surfaces to be welded, transforming the joint contact from a point into an extended contact area. The surfaces are welded by the action of the current flow given by the first pulse (50–60 Hz). They reach a temperature that is equivalent to 70% of the melting temperature of titanium (data measured by a thermocouple). In this way, the joining is obtained in a very short time. The impulse application time must be strictly controlled because a short timeline is important to maintain the correct temperature at the interface. Then, a second current pulse is applied. It causes a heating at a temperature higher than alpha to beta transition (data measured by a thermocouple). A constant pressure and argon flux has been maintained (when it was used) until the cooling of the joint (ten seconds).

2.2. Joining characterization

As first, joining between two titanium wires (1.5 mm in diameter) was realised as a model for a preliminary analysis of the intraoral welding technique (wire–wire samples).

The effect of different welding parameters on the quality of the final joining was investigated. Four typologies of joining were studied, varying the number of applied electric impulses and the atmosphere during welding: one electric impulse without Argon flux (1 imp – AIR), one impulse with Argon flux (1 imp – Ar), two impulses without Argon flux (2 imp – AIR), two impulses with Argon flux (2 imp – Ar).

Samples were observed in sections in order to characterize the welded area.

Friction occurring during cutting of the sections could introduce artefacts on the joining area, so, in order to avoid them, the wires near the joining were carefully removed by grinding and polishing, till exposition of the section of the joining, as described by the authors in (Ferraris and Spriano 2010). The exposed section of the joining was mirror polished with abrasive papers (up to 4000 grid) for optical and electronic microscope observations.

Then surfaces were prepared for metallographic investigations: the samples were acid etched with Kroll solution, in order to highlight the microstructure in the welded zone as suggested by Iijima et al. (2008) and in the Struers technical note (Taylor and Weidmann, 2015) and then observed again by means of optical and electron microscopy.