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The role of welding techniques in the biomechanical behavior of implant-supported prostheses

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ABSTRACT

This in vitro study investigated the role of welding techniques of implant-supported prostheses in the 2D and 3D marginal misfits of prosthetic frameworks, strain induced on the mini abutment, and detorque of prosthetic screws. The correlations between the analyzed variables were also investigated. Frameworks were cast in commercially pure titanium (cp-Ti). A marginal misfit of 200 μm was simulated in the working models (control group) ($n = 20$). The 2D marginal misfit was analyzed according to the single-screw test protocol using a precision optical microscope. The 3D marginal misfit was performed by X-ray microtomography. Strain gauge analysis was performed to investigate the strain induced on the mini abutment. A digital torque meter was used for analysis of the detorque and the mean value was calculated for each framework. Afterwards, the frameworks were divided into two experimental groups ($n = 10$): Laser (L) and TIG (T). The welding techniques were performed according to the following parameters: L (390 V/9 ms); T (36 A/60 ms). The L and T groups were reevaluated according to the marginal misfit, strain, and detorque. The results were submitted to one-way ANOVA followed by Tukey's HSD test and Person correlation analysis ($\alpha = 0.05$). Welding techniques statistically reduced the 2D and 3D marginal misfits of prosthetic frameworks ($p < 0.001$), the strain induced on the mini abutment replicas ($p = 0.006$), and improved the screw torque maintenance ($p < 0.001$). Similar behavior was noted between L and T groups for all dependent variables ($p > 0.05$). Positive correlations were observed between 2D and 3D marginal misfit reading methods ($r = 0.943$, $p < 0.0001$) and between misfit and strain (2D $r = 0.844$, $p < 0.0001$ and 3D $r = 0.864$, $p < 0.0001$). Negative correlation was observed between misfit and detorque (2D $r = -0.823$, $p = 0.003$ and 3D $r = -0.811$, $p = 0.005$). In conclusion, the welding techniques improved the biomechanical behavior of the implant-supported system. TIG can be an acceptable and affordable technique to reduce the misfit of 3-unit Ti frameworks.

1. Introduction

Implant-supported rehabilitation is considered a successful approach to treat partially and completely edentulous patients, allowing the restoration of their function and aesthetics [1,2]. Different materials are applied to fabricate implant-supported frameworks [3], and the use of titanium (Ti) material increased [4,5] due to its biocompatibility and biomechanical characteristics such as low density, high mechanical strength, high corrosion resistance, and high ductility [6–8]. However, as for other alloys, the laboratory and clinical fabrication steps of implant-supported prostheses such as casting or machining can potentially generate alterations of the fit of Ti frameworks [9].

The presence of misfit in an implant-supported prosthesis can transfer the stress to the implant-supported system, which may lead to biological and mechanical complications [4,10,11] such as loosening or fracture of retention screws and compromised osseointegration [10]. This is expected because the bone tissue and implants are rigidly connected, which does not allow the dissipation of stresses [12]. The stress development occurs even without the presence of functional loads, where the presence of misfit is able to induce stress levels on the implant-supported system [10,13]. Unfortunately, the presence of misfit levels is a clinical reality [14] and values ranging from 10 to 150 μm are defined as clinically acceptable [10,13–15]. However, despites these values have been reported and used as reference, they are empirically based. Thus, minimum misfit values should be targeted for the fabrication of implant fixed prostheses [15].

Different fit-corrective techniques are used to reduce the misfit of implant-supported prostheses including spark erosion [16,17] and welding techniques [18–21]. Welding techniques have been widely

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used to reduce framework misfit [20,21]. Beyond the reduction of the misfit, these techniques' advantages include decreasing the stress on the implant-supported system [20,22]. Different welding technologies such as Light Amplification by Stimulated Emission of Radiation (Laser) welding [20,21] and Tungsten Inert Gas (TIG) welding are available [23,24]. TIG welding is performed using an electric arc formed by the contact between the metal of the framework and a non-consumable tungsten electrode [23]. Because of the reactivity of the electrode and region to be welded with the air gases, the surfaces during TIG welding need inert gas protection, usually argon, combined or not with other gases such as helium [20,23–25]. Furthermore, TIG technique allows welding in any position and achieves high-quality welds with excellent finishing [20,25]. The Laser welding technique uses a concentrated, coherent, monochromatic, and high-energy light beam to generate heat concentration in the area to be joined [21,25]. Due to the high heat concentration, the metal melting point is achieved and the joint region is filled by the melted metal [25]. Although both welding techniques have been widely used [20,21,23], the influence of these methods on the misfit and stress levels of commercially pure titanium (cp-Ti) frameworks remains unclear.

Concerning the marginal misfit measurement used in in vitro studies, the trivial method performed is the two-dimensional (2D) technique, which allows the reading of a single axis of misfit using a precision optical microscope [13,16,26]. In this technique, the misfit is a vertical difference between the mini abutment platform and the top edge of the framework [13,16,26]. However, 2D misfit reading technique does not allow the internal misfit reading. Otherwise, this can be achieved using the three-dimensional (3D) technique. Three-dimensional misfit reading technique allows volumetric reading of the gap between the abutment and framework [27–32]. Although the 3D technology is an advanced technique for misfit reading, it is more expensive and time-consuming than the 2D technique. Also, despite some studies recommending 3D technique as a more accurate misfit reading technique [31,32], the superiority of 2D or 3D techniques is not yet well established. Thus, a comparison between the 2D and 3D techniques is needed.

The purpose of this in vitro study was to evaluate the effect of welding techniques on the 2D and 3D marginal misfits, strain, and detorque of prosthetic screws in 3-unit prosthetic frameworks. Correlations between the dependent variables were investigated. The research hypotheses were as follows: (i) Laser and TIG welding techniques would influence the misfit, strain, and prosthetic screw stability in the implant-supported system, (ii) a positive correlation between the 2D and 3D marginal misfit reading methods would be found, (iii) a positive correlation between misfit and strain values would be detected, and (iv) a negative correlation between marginal misfit and screw detorque would exist.

2. Material and methods

2.1. Experimental design

Twenty frameworks were cast in cp-Ti, simulating a 3-unit inferior fixed partial denture. A marginal misfit of 200 μm was simulated using two working models (control group). The 2D and 3D marginal misfits, the strain induced on the mini abutment, and the detorque values of prosthetic screws were investigated. Afterwards, the 20 frameworks of the control group were divided into two experimental groups: Laser (L) and TIG (T) (n = 10). The same analyses were performed in the welded groups (Fig. 1). Fig. 2 shows all the prosthetic components used in the present study.

2.2. Fabrication of prosthetic frameworks

A metallic master model in stainless steel was fabricated to simulate the clinical situation of two implants placed on the region of the inferior first premolar (PM) and first molar (M) (Fig. 3). Two modified mini abutment replicas of a 4.1 mm platform (Neodent, Curitiba, PR, Brazil) were placed for waxing the framework. From the waxing standards, 20 frameworks were cast in cp-Ti. These frameworks represented the control group (n = 20).

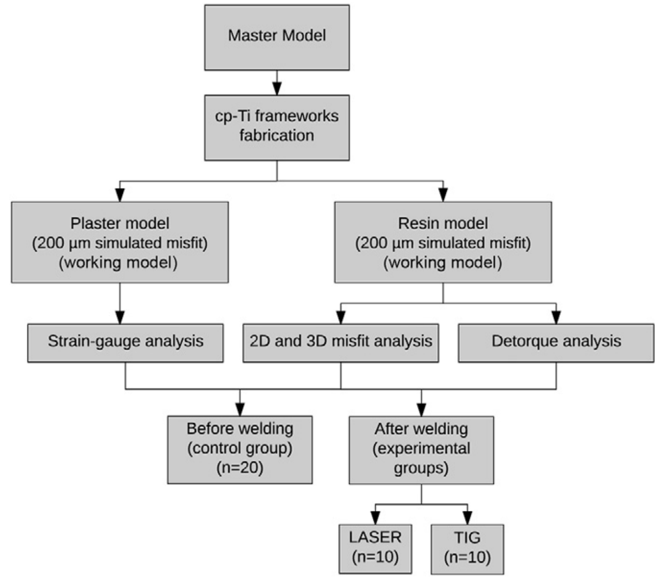

Fig. 1. Flowchart of study methodology design.

2.3. Vertical marginal misfit simulation

Two types of working models were fabricated in epoxy resin (Araldite, Araltec, Guarulhos, SP, Brazil) and in plaster (Durone Dentsply, Petropolis, RJ, Brazil). The epoxy resin model was used for the 2D and 3D marginal misfit analyses and screw detorque analysis, while the plaster model was used for strain gauge analysis. A rigid model is necessary for the strain gauge measurement due to the fragility of the gauges. The plaster and epoxy resin models were fabricated containing two 4.1 mm modified mini abutment replicas and two mini abutment replicas, respectively [26]. External hexagon connection was used for all models. A marginal misfit of 200 μm was simulated in the working models using a steel ring of 200 μm thickness placed between the mini abutment replica M and the framework. Such a misfit level is considered clinically unacceptable in the literature, due to the development of overstress on the implants and prosthetic components of the fixed partial denture [10,21]. A clinical unacceptable misfit level was

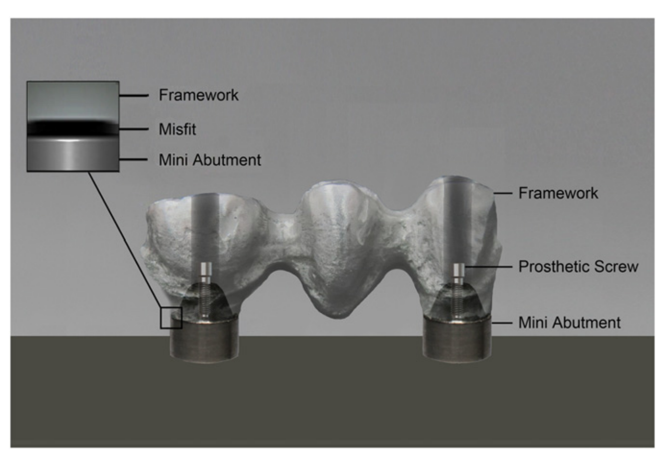

Fig. 2. Nomenclature of prosthetic components.