Original Article

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Implant-supported titanium framework: photoelastic analysis before and after spark erosion procedure

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Abstract

Aim: This study used a photoelastic analysis to evaluate the passive fit of titanium cast laser welding frameworks before and after spark erosion procedure. **Methods:** A stainless steel cast was used in order to reproduce a human mandible. Five Multi-Unit abutment analogs were attached to this cast and 6 frameworks were produced in commercial pure titanium. The cast was molded and a photoelastic matrix was produced incorporating 5 dental implants with Multi-Unit abutments. All samples were subjected to a laser welding. The precision of adjustments within a range of 0.5 μm was evaluated under microscope observation. The best fitted framework was selected and subjected to a photoelastic analysis (Group I). The tightening of the screws was in 3 predetermined sequences (1,2,3,4,5/ 5,4,3,2,1/ 3,2,4,1,5). Then the same framework was subjected to a refinement by spark erosion technique (Group II) and evaluated by photoelastic analysis. **Results:** The sequence (3,2,4,1,5) achieved better results in both groups. A larger number of fringes were observed around the median implants in all sequences in both groups. **Conclusions:** The titanium cast laser welded frameworks processes associated with spark erosion procedure improves significantly the marginal framework adaptation and is effective for its passive fit.

Keywords: titanium, misfit, implant, framework.

Introduction

The use of implant-supported prostheses has achieved a significant success in edentulous patients, providing retention and prosthetic rehabilitation. The biomechanical aspect of an implant is fundamentally different from that of a natural tooth overloading an implant. There is the possibility to transfer excessive load to the implant and consequently from this to the circumjacent bone, which may exceed the physiologic limit and cause bone loss around the implants[1]. Promoting a passive fit between the implants and the framework is a predictable manner to achieve a reliable prosthetic treatment over implants[2-3]. A previous review article showed that among several procedures to improve passive fit in implant-supported prostheses, laser-welding[4] and electrical discharge machine (EDM) refinement gave the best results[5]. Titanium frameworks improved by laser-welding showed better adaptation over the implants when compared to the conventional welding on fine alloys[6].

EDM allows overcoming the issues related to accuracy and passive fit of metallic frameworks and its usage has been justified due to a variety of alloys that

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can replace the conventional gold prosthesis, which has excellent passive fit and has been used since 1982[7-8]. Many researchers working with microscopic analysis, strain gauges and finite element have introduced other methods to evaluate the passive fit of implant-supported prosthesis[8-13]. Laboratorial procedures are extremely important to evaluate the best technique to be used in clinical situations and the photoelastic analysis is an experimental method that allows verifying the stress caused by the frameworks and their design. This method provides information in colored fringes of visible light viewed through a polariscope which helps to establish the stress level[14].

In dentistry, the photoelastic analysis has been largely used in order to evaluate the stress level on implant-supported prostheses allowing the global evaluation of stress in a specific component[14-15]. This procedure enables having a quality analysis of the stress level through the optical effect patterns caused by the frameworks over the photoelastic cast. Considering the statements above, the aim of this study was to establish a comparison between frameworks before and after the EDM procedure by the sequence of screw tightening.

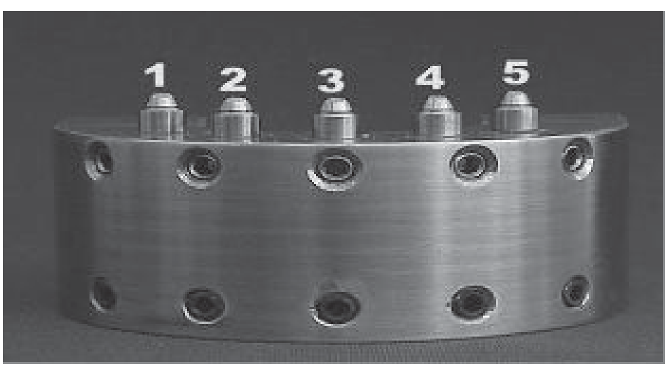

Fig.1. Master model with implant abutments (Frontal view).

Material and methods

A stainless-steel matrix was manufactured to simulate an edentulous mandibular arch. Five parallel orifices were made in the matrix based on the design defined by a classic protocol[16] and five multi-unit analogs (Conexão Sistema de Próteses, São Paulo, SP, Brazil) were installed in each orifice. Each analog was fixed by one screw located horizontally in the master cast and defined as 1, 2, 3, 4 and 5 (Fig 1).

Six titanium framework groups were produced to fit the analogs (Tritan; Dentaurum, Germany). Five Multi-Unit cast cylinders were linked by a 4mm diameter blue wax profile (Dentaurum Pforzheim, Germany).

PK Opaque wax was applied between the blue wax (Dentaurum Pforzheim) and the cast cylinders to provide better connection. A standard 10-mm-long blue wax was left as a cantilever. After waxing the framework it was put in a heatproof lining to the pre-heated electrical machine (Vulcan 3-550-NDI Box Furnace Degussa Ney Dental Inc Yucaipa, CA, USA).

After pre-heating, the framework was settled in the casting machine Rematitan (Dentaurum Pforzheim) and a 31 g-titanium block was automatically injected. Laser welding was performed using a desktop laser welding machine

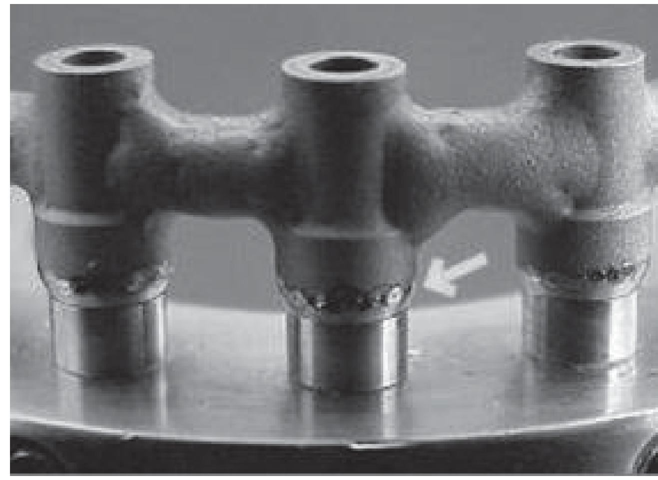

Fig. 2. Laser-welded cylinder framework.

(Dentaurum JP Winkelstroeter KG Pforzhein, Germany). The titanium cylinders were screwed between the Multi-Unit analogs and the framework, and the framework-cylinder interface was welded. In order to minimize any deviation during the welding procedure one weld point was initially applied to the vestibular, lingual, mesial and distal surfaces. The welding procedure was completed by overlaying the welding points in about 60% (Fig 2).

After laser welding all samples, the misfit of each framework in both groups was evaluated with an optical microscope (STM Digital Olympus, Japan) with 0.5-µm precision and x30 magnification. A gypsum index standardized the stainless-steel matrix position on the microscope dish. To take measurements, the frameworks were placed on the metallic matrix and the titanium screw (Immediate Loading Prosthetic System; Conexão Sistema de Próteses,) that corresponds to implant "1" was tightened with a 10 Ncm torque force measured by a torque machine (Immediate Loading Prosthetic System; Conexão Sistema de Próteses,) and the misfit of the component "5" was evaluated. The same procedure was done on abutment "5" and the misfit in abutment "1" was evaluated[17].

Each abutment was measured three times on the buccal (B) surface and three times on the lingual (L) surface and their averages calculated. The micrometric head ran from the previously marked abutment border up to the line located on the prosthetic cylinder on axis *x*.

Only the framework that demonstrated the best fit of each group was used for the photoelastic analysis. The square refinement tools were placed into the Multi-Unit frameworks on the metallic matrix through a long fit screw to obtain the photoelastic model.

In order to produce the transfer mold, the long fit screw was connected to a dental floss and to the acrylic resin (Pattern Resin; GC Corporation, Tokyo, Japan) using the "Nealon" technique to keep the stability of the structure and the position of the abutment. After the acrylic resin polymerization the structure was split and reconnected using the same refinement tools.

Once all frameworks were connected, the metallic matrix was placed in the middle of a plastic cylinder (10.0 cm diameter x 5.5 cm high) for support for the molding procedure.

Laboratorial silicon (Silibor; Clássico Produtos Odontológicos Ltda., São Paulo, SP, Brazil) with 48-hour curing time was used to duplicate the stainless steel matrix. After curing, the long fit screw was removed and the metallic matrix taken from the silicon mold. Five Multi-Unit abutments were connected at 20 Ncm tightness measured in a torque machine (Clássico Produtos Odontológicos Ltda.) to the Connect AR™ implants (4.1 mm diameter x 13.0mm long; Clássico Produtos Odontológicos Ltda.). The whole assembly was installed to the transfer in the mold. The mold was filled with a photoelastic resin (Araldite; Huntsman LLC, Salt Lake City, UT, USA) that has two components: the GY-279 modified with dilute reactive agent of low and medium viscosity composed of a biphenyl-A basis and the catalyst HY-2964 composed of cycloaliphatic amine as basis.

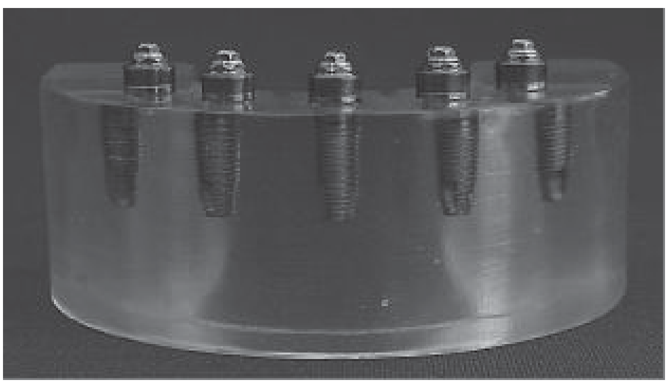

Fig. 3. Photoelastic acrylic model.

Measurements were taken in a test tube and the handling of the resin took a Becker. In order to get a uniform mixture, the catalyst was added to the resin in a glass tube and vigorously stirred. The bubbles formed from the stirring were eliminated in a vacuum chamber at 750 mm Hg of internal pressure for 20 min.

As recommended by the manufacturer, the photoelastic model was covered and left undisturbed for 72 h in order to disassemble the model from the mold (Fig 3). The use of polariscope on the stress analysis allows a better view of the stress distribution on the structure. This enables to accurately determine the stress level around the implants when bright colored fringes are observed due to the polarized light dispersion through a photoelastic material.

The analysis of stress distribution through photoelastic structure was made taking in account the images generated by the circular polariscope, connected to a digital camera to focus the fringes and to record the images. The pictures were taken for each sequence of screw tightening.

The photoelastic analysis by counting the number of fringes around each abutment showed the magnitude of the stress and the distance in between fringes. A predetermined colored order of fringes, classified as lower or higher order, was used to identify the stress of the fringes (Fig 4)[17-18]. This technique transforms the internal mechanical stress, produced in complex geometric structures, into visible light patterns of colors that indicate the areas and the magnitude of stress.

To establish a possible connection between the level of framework misfit and the level of stress around the abutments, the frameworks were installed in the following tightening

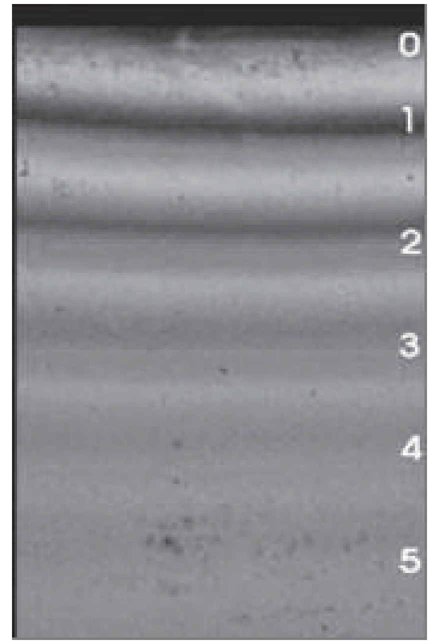

Fig. 4. Predetermined order of fringes to determine the intensity of stress.

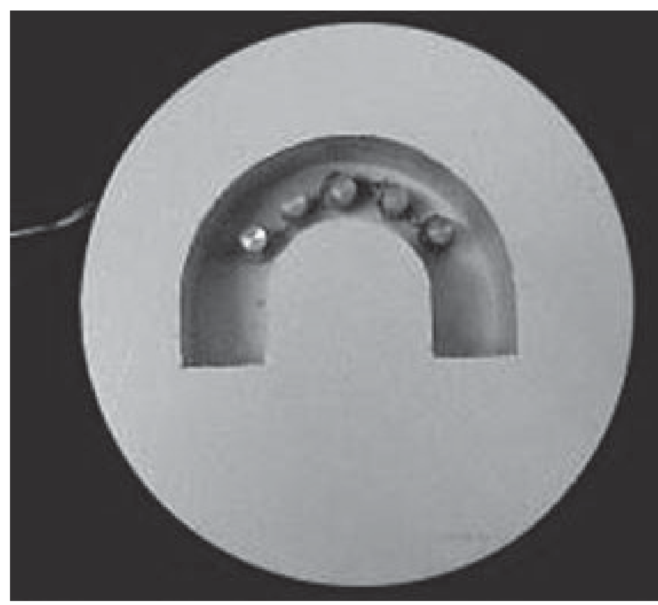

Fig. 5. Copper cable passing around copper analogous.

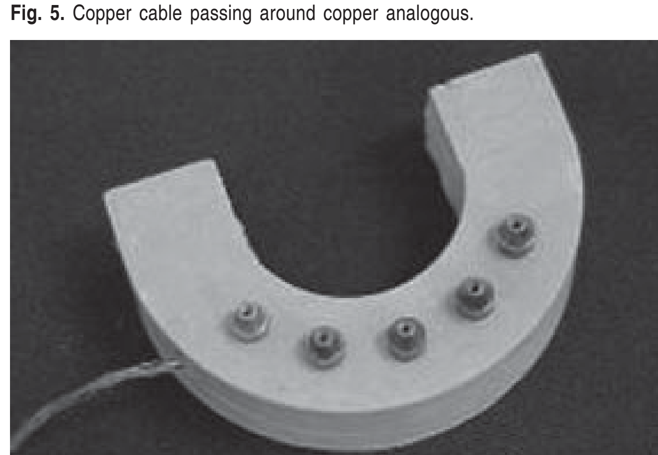

Fig. 6. Gypsum structure and copper analogous.

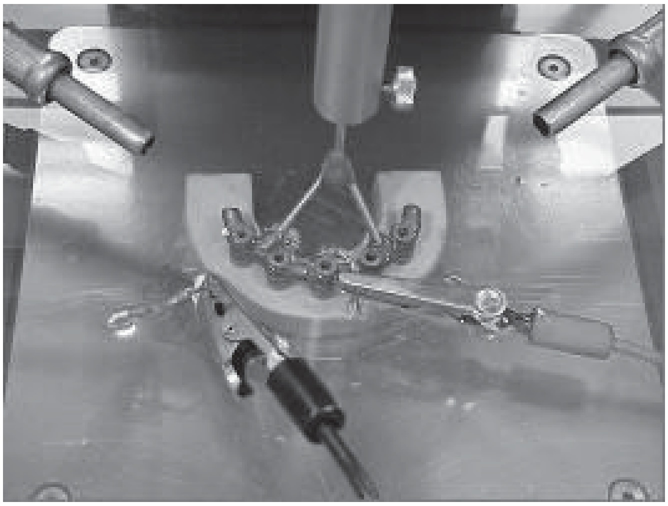

Fig. 7. Electrical discharge procedure: framework and cupper analogous immersed in dielectric liquid.

sequence: abutments 1, 2, 3, 4, 5; abutments 5, 4, 3, 2 , 1; abutments 3, 2, 4, 1, 5.

After having shot the pictures of each sequence, the photoelastic model was placed into an oven at 50°C for 20 min to release the stress. The titanium frameworks were placed in the Electrical Discharge Machine (Tel Med Technologies Port Huron, MI, USA) and high voltage electrical discharges were released with the objective to connect pieces within a precision of 0.01 mm. The transference of abutments of the metallic matrix enabled to obtain a gypsum model with copper analog abutments threaded by a copper cable for the electrical discharge procedure. (Figs. 5 and 6).

The titanium framework was fixed to the vertical rod using a proper glue (Quick Lock; Tel Med Technologies Port Huron), settled to the gypsum mold without connection to the positive pole (red electrode), and plugged into the negative pole (black electrode). In order to start the electrical discharge, the gypsum structure model and the metallic framework were immersed in a dielectric liquid (Tel Med Technologies Port Huron) to reduce the conductivity, to insulate and cool off the structure[18] (Fig 7). The vertical rod movements were controlled by the lower surface that also controlled the power intensity and the frequency of the released electrical discharges (250,000/s). The temperatures generated by the power between the copper electrode and the structure ranged from 3000°C to 5000°C, evaporating the metal refining the cervical finishing[19]. Full adjustment of structure was visually shown after 8 h. The photoelastic analysis was performed again in the sequence of screws mentioned before.

Results

From the welded laser structure without electrical discharge refinement, the following results can be considered:

Photoelastic analysis considering the prosthetic screw tightness: Sequence 1/2/3/4/5. The digital pictures showed that after tightening the first screw some stress was released from the apical region of abutment 1. Following the sequence and tightening the abutment 2 and 3, respectively, more stress was generated as shown on the photoelastic fringes at abutment

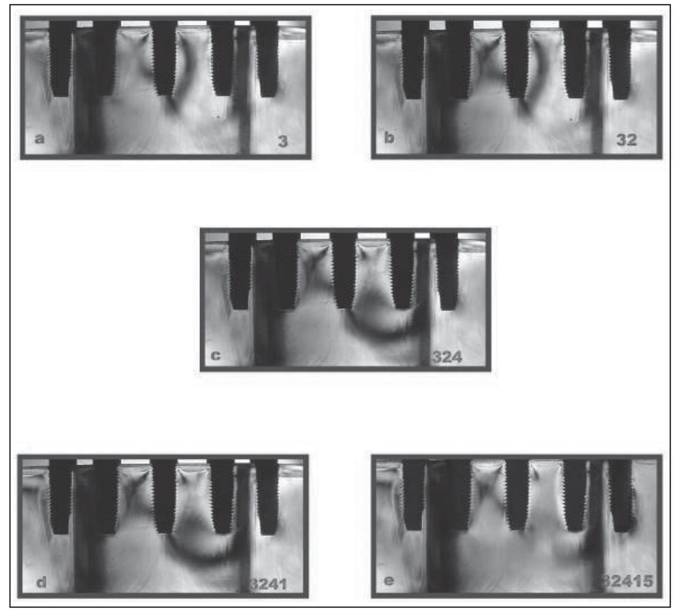

Fig. 8. Photoelastic analysis of group I - tightening sequence: 3/2/4/1/5 (a, b, c, d, and e, respectively).

distal 2 and abutment mesial 3. The fringes, which appeared around the abutments 2 and 3, reduced to a lower photoelastic order after tightening the screws 4 and 5 and the stress was more homogenous around the apical region of the 5 implants.

Photoelastic analysis considering the prosthetic screw tightness: Sequence 5/4/3/2/1. In this sequence, there was a gradual increase of stress as identified by the photoelastic fringes. The stress was concentrated on the mesial and distal surfaces of the cervical region. Stress was greater around abutments 4 and 3 with no change when the screws 2 and 1 were tightened.

Photoelastic analysis considering the prosthetic screw tightness: Sequence 3/2/4/1/5 (Fig 8). Stress, and therefore fringes, was generated on mesial, distal and cervical regions when tightening the screw on the implant 3. When the screw 2 was tightened, the fringes on implant 3 did not reduce. Tightening screw 4, the fringes grouped due to a great concentration of stress between the distal region of implant 3 and the mesial region of implant 4. Fringes increased at the apical region of implants 3 and 4. The stress observed after tightening the sequence reduced the concentration of fringes and stress. More homogenous stress distribution was observed at implant 5.

Laser welding framework after electrical discharge gave the following results:

Photoelastic analysis on the prosthetic screw tightness: Sequence 1/2/3/4/5E. Higher stress was observed on THE distal region after tightening screw 1. The tightening of screws 2 and 3 showed a concentration of fringes on the mesial, cervical and apical regions of implant 2 and on the mesial and distal regions of implant 3. However, the photoelastic fringes around implant 2 reduced to a lower order after tightening screws 4 and 5 and the stress showed better distribution.

Photoelastic analysis on the prosthetic screw tightness: Sequence 5/4/3/2/1E. The stress was located on the top of implant 5 and reduced to a lower photoelastic order when

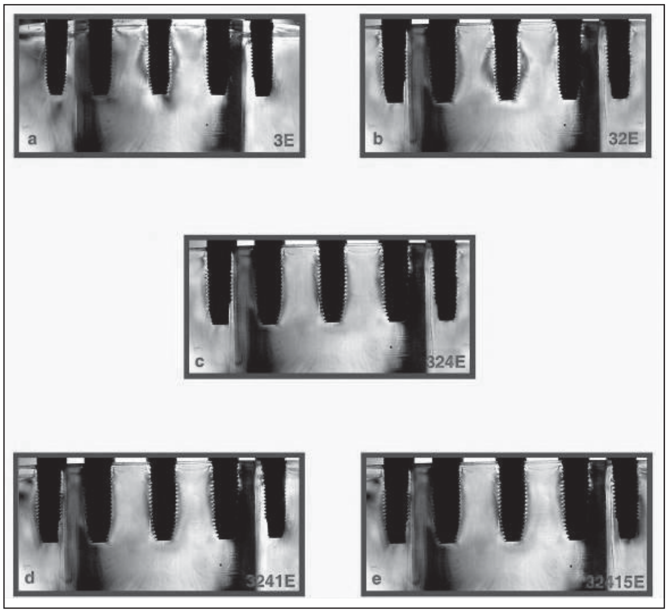

Fig. 9. Photoelastic analysis of group I - tightening sequence: 3/2/4/1/5E (a, b, c, d, and e, respectively).

implants 4 and 3 were tightened. Colored fringes that indicate less stress could be observed around and on top of implants 4, 3, 2 and 1. After tightening the prosthetic screws (5, 4, 3, 2, 1), the fringes were observed around the implants.

Photoelastic analysis on the prosthetic screw tightness: Sequence 3/2/4/1/5E (Fig 9). The screw tightened on implant 3 produced photoelastic fringes around implant 3, on the distal, mesial and apical regions. However, when the screw was tightened on implant 2, the stress located at the apex reduced. On this sequence of tightening the screws, the stress was similar in all implants, with lesser photoelastic fringe formation around all implants homogeneously. Less stress was induced on the implants in this sequence.

Discussion

Several methods to evaluate the passive fit of implant prosthesis have received great attention from the scientific community[20-23]. This study used the photoelastic analysis to determine the stress level on the framework, analyzed in the polariscope. However, it could be verified that the stress generated by the tightening of screws on the structure in the photoelastic cast had a different pattern at the apical region from the side region of implants. This demonstrates a non-uniform distribution of stress. The photoelastic analysis is highly indicated to evaluate the distribution and the quality of stress level produced by screw tightening[21-23].

In this study, the photoelastic analysis qualitatively described stress distribution. It may measure how certain transparent materials show photoelastic fringes when stressed under the polarized light. The larger the number of fringes, the larger the stress produced. However, other colors not strictly related to the fringes can also indicate some stress level[21-23].

The results of this study showed an important difference from the fringe standards on the photoelastic mold and laser welding when compared to the results on the framework undergone to laser welding and electrical discharge technique.

The photoelastic analysis, however, has some limitations. It is necessary to calibrate the method of evaluation of the colored fringes, and then, the examiner will classify the stress generated around the implants. The result may be near to the real, but it is subjective. Comparing the results of the photoelastic analysis to other method of stress evaluation, as strain gauges, is a valuable way to confirm the results.

Within the limitations of this study, the following conclusions were drawn:

1. The stress generated around the implants before or after the electrical discharge application was more evident on mesial implants than on the distal ones.
2. The sequence 3,2,4,1,5 associated with electric discharge application showed better results after all prosthetic screws had been tightened.
3. Distal implants clinically overloaded by the cantilever extension in fixed implant-supported prosthesis was less stressed using the sequence of tightening the screws from the medial to distal direction of a framework when associated with laser welding and spark erosion.
4. The laser welding technique together with the electrical discharge improved significantly the metallic framework connection on the photoelastic cast as indicated by the reduction of stress around the implants.

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