Stress Analysis on Single Cobalt/Chrome Prosthesis With a 15-mm Cantilever Placed Over 10/13/15-mm–length Implants: A Simulated Photoelastic Model Study

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The aim of study was to assess the stress around 10/13/15-mm implants in the mandibular area with a 15-mm cantilevered acrylic-resin-coated prostheses following the application force, using the photoelasticity method. Three photoelastic mandibular models were created containing 10-, 13-, and 15-mm implants in length and 3.75 mm in diameter. The implants had bore internal hex connections and were placed parallel to the intermental region. Abutments with 1-mm high cuffs were placed over the implants, and a single cobalt/chrome metallic prosthesis with a 15-mm cantilever, coated with thermoplastic acrylic resin, was placed on top. Loads of 1.0 and 3.0 bars were applied, and the images were photographed and assessed by photoelasticity method. The greatest stress levels were observed for the 10-mm implants. The stress pattern was the same regardless of implant length; only the magnitude of the stress along the implant body revealed changes. Increased implant length played a role in reducing stress on the investigated area of the model, and the 15-mm implants exhibited the best performance in regard to stress distribution. The highest stress levels were found in the implants closest to the cantilever and the central implant. The longest implants were more favorable in regard to the stress distribution on the peri-implant support structures in the 15-mm cantilevered prosthesis under loads.

Key Words: dental implants, stress, mandible, load

INTRODUCTION

According to the classic protocol,¹ a 2-stage surgery is needed for implant placement in fully edentulous mandibles. During the first stage, 4 to 6 titanium implants with 3.75-mm diameters are placed in the anterior portion of the mandible between the mental foramen. A healing period of 4 to 6 months is recommended before the second surgical stage, during which a fixed total prosthesis holding stock teeth using a metallic superstructure and a 15- to 20-mm cantilever are placed.² Importantly, this prosthesis is exposed to axial and tangential occlusal forces that are distributed around the implants as a function of the geometry of the prosthetic component.³–⁶ Although this type of prosthesis has been used for several years and its results are predictable,⁷–⁹ the issue of stress induction must always be considered in this type of rehabilitation because is known that larger cantilevers may overload the implants, leading to risk of failure.¹⁰,¹¹ This way, an increase in implant length may improve the stress distribution to surrounding tissues¹¹–¹³; therefore, the null hypothesis is that the stress distribution is the same with 10/13/15-mm implants as with a 15-mm cantilever prostheses. The aim of the present study was to assess whether or not the stress around 10/13/15-mm implants in the mandibular area with a 15-mm cantilevered acrylic resin coated protocol-type prostheses, following application of force, is different according to implant length when using the photoelasticity method.

MATERIALS AND METHODS

Test specimens

The photoelastic resin Araldite (Araltec Produtos Quimicos, Guarulhos, São Paulo, Brazil) was used to develop the test specimens.

Photoelastic skull

A photoelastic skull served as a model to simulate the mandible using Novox resin—a Novox Base, alcohol polymer, and Novox Activador mix of organic components (Talladium International,
Lleida, Spain), used to create prototype test specimens and subsequently conduct photoelastic assays.

### Loading device

A pneumatic device for load application was used to successively apply 1.0 and 3.0 bar pressures on the photoelastic model from the mandible toward the maxilla. A piston with an area of 4.42 cm² transmitted the pressures. The ratio of pressure to applied force as a function of the 4.42 cm²-piston area is described in the Table.

<table>
<thead>
<tr>
<th>Pressure/Bar</th>
<th>Force/Newton</th>
<th>Resultant/Kilogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>44.2</td>
<td>4.5</td>
</tr>
<tr>
<td>3.0</td>
<td>130.0</td>
<td>13.5</td>
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</table>

### Implants selection and placement

The test specimens were comprised of three photoelastic models, including 5 implants each. The implants had 3.75-mm diameters, internal hexagons, a uniform length of 10, 13, or 15 mm for each model, and a cobalt/chrome metallic superstructure coated with thermoplastic acrylic resin to simulate a screw-retained system. Implants were placed between the mental foramen in all three models.

### Bite registration

A wax base plate with a plane of orientation was created on the duplicate resin mandible to fixate the mandible relative to the maxilla; this was produced using plaster and fixated to the upper arm of a semi-adjustable articulator. The vertical dimension of occlusion was calculated from the vertical maxillary-mandibular distance using a Willis gauge. Once the maxillo-mandibular record was taken between the upper arch and the implant mandible, the plane of orientation, the mandible was fixated to the lower arm of the articulator. The next stage consisted of mounting the ready-made Art Plus A3, U36, and U85 acrylic teeth following the position of the upper teeth and the previously established vertical dimension. Occlusal adjustment was performed using occlusal marking film (AccuFilm, Parkell, Edgewood, NY) to achieve the most simultaneous and bilateral contacts.

### Surgical guide

The tooth-mounted plate was produced using silicon (ZetaLabor, Zermack, Italy) and used to create a surgical guide made of transparent acrylic resin. The sites selected for implant placement were marked on the surgical guide using the Brånemark system implant distribution as reference.

### Master model

Using this technique, the master model simulated an edentulous mandible with five intermental Micro Unit implant analogs (Conexão Sistema de Prótese, São Paulo, Brazil).

### Superstructure and infrastructure

Five ready-made plastic cylinders without an anti-rotation device for the Micro Unit abutments (Conexão Sistema) were used to wax the superstructure. The infrastructure was waxed within the vestibular-lingual and occlusal-gingival boundaries using the 15-mm distal extension or cantilever from the posterior implants so that the length of the implant sufficed for an occlusal support up to the level of the first maxillary molars.

### Procedures

The superstructure was created from molten cobalt/chrome (StarloyC, DeguDent Dentsply, Hanau-Wolfgang, Germany), sectioned, returned to the master model to which it was first joined using Duralay resin (Duralay Reliance Manufacturing Co, Chicago, Ill), and welded to achieve a better adaption quality. After welding, the superstructure was again screwed to the mandible that was placed in the articulator and joined to the surgical guide using Duralay resin. Once the structure was joined to the surgical guide, the position of the implants was transferred to the Novox resin mandible. After transferring the implants to the mandible, the free ends of the infrastructure were measured using a caliper and then cut using a carborundum disc to adjust the arms to 15 mm. At this time, the superstructure was ready for the application of 1 layer of the Vipi-Tone light-pink opacifying agent (Vipi Indústria, Comércio, Exportação e Importação de Produtos Odontológicos Ltda, Pirassununga, São Paulo, Brazil).

Once the structure was opacified, the tooth-mounted plate was fixated to it, and the acrylic coating was applied. The coated superstructure was coupled to the resin mandible, and the occlusal adjustment of the prosthesis screwed to the mandible was performed to achieve the most simultaneous and bilateral contacts with the maxilla of the photoelastic skull. The next stage involved the production of the mandible/prosthesis set using Dow Corning reproduction silicon (D’Altomare Quimica, São Paulo, Brazil) to elaborate the photoelastic models. The Araldite GY2798 photoelastic resin (Araltec Produtos Quimicos Ltda, Hunstman, Guarulhos, São Paulo, Brazil) was used to create the photoelastic model. Three photoelastic models were developed differing only by the length of the implants (Figure 1a through c). For the purpose of standardization, the prosthetic structure of the test specimens was 15 mm long, which reduced the occlusal platform along the vestibular-lingual direction and relieved occlusion.

An important condition for the success and maintenance of osseointegration is achieving the most passive fit of the prosthesis as possible over the implants. To minimize distortion, maladjustment, and stress in the photoelastic model, the implants were placed in the resin mandible only after the prosthesis was built. Another relevant factor is the manner in which the model was supported on the platform, given that this support transmits the load to the set composed of mandible, implants, prothetic abutments, and the cantilevered prosthesis. Therefore, in addition to ensuring that the base was well affixed to the model, the support stabilized the entire experimental set to keep the direction of the load constant as obtained during occlusal adjustment.
Stress Analysis on Single Cobalt/Chrome Prosthesis

Occlusal Adjustment

Occlusal adjustment was performed such that the occlusal contacts were able to transmit the axial load in a simultaneous and bilateral manner, thereby achieving stability and balance.

Photoelastic Analysis

A circular polariscope was used in the experiments. To improve image sharpness, the models and the device used for load application were immersed together in a tank containing pure mineral oil, which allowed for a better visualization of the (color) isoclinic fringes. Thus, a photographic light reflector and a light diffuser were coupled to the polariscope. The full set was designated as a photoelastic stress meter.

Photography

A photoelastic analysis was performed to investigate the effect of stress, which was recorded using photographs. Frontal photographs were acquired from all 3 photoelastic models to analyze the results prior to load application.

RESULTS

To facilitate the interpretation of the results, Figure 2 illustrates the assays performed with Models 10, 13, and 15 (MD10, MD13, and MD15, respectively) without the application of pressure, as well as with 1.0- and 3.0-bar pressures. The implants in the photographs were numbered from 1 to 5, left to right. The MD15 model exhibited fewer fringes around the 15-mm implants, denoting less stress compared with the MD10 and MD13 models. The stress distribution pattern along the implants was constant throughout the experiment, regardless of their length. However, changes were found with regard to stress intensity, which decreased as the length of the implants increased. When the load was increased from 1 to 3 bars, stress increased in both the mesial and distal faces of the cervical portion of the most distal implants, as well as in the middle and apical thirds of the right distal implant. Right and left photographs were taken of the models when a 3.0-bar load was applied (Figure 3). The 10-mm implants exhibited stress with many fringes around them, and the 15 mm implants exhibited less stress around them. The stress distribution pattern was the same across all investigated implant lengths, whereas only the magnitude of stress along the implant body changed.

The longest implants were more favorable with respect to the load distribution of the peri-implant support structures, and the distal and central implants suffered the most stress.

DISCUSSION

With the photoelasticity analysis method, it is possible to locate the tensions that occurred around the implants\(^{14}\) and, according to the literature, this method is relatively simple and reliable as correlation of clinical findings are observed.\(^{15}\) With the absence of the periodontal ligament, biomechanics for an implant is different from that of a natural tooth, given the possibility of transferring excessive load to the implant and the adjacent bone, which could result in exceeding the physiological limits causing the loss of osseointegration. The load is not always harmful but cannot exceed the physiological limits.\(^{16}\)

While there are studies of stress distribution on bone and implants according to the occlusal load, the current study compares this distribution using different implant lengths in the presence of a cantilever, which is a relatively common clinical situation. The photoelastic analysis of the 10-mm implants showed that only the central implant exhibited minimal stress in the load-free condition, whereas the other implants were virtually stress free. Thus, the corresponding image was used to assess the effect of stress. When the load was increased from 1 to 3 bars, stress increased in both the mesial and distal faces of the cervical area of the most distal implants, as well as in the middle and apical thirds of the right distal implant. These findings match those of other studies\(^{17-20}\) conducted with fixed prostheses over cantilevered implants, which also found that greater stress in the implant closest to the cantilever. However, other studies\(^{21}\) performed under the same conditions found that the greatest stress occurred at the cervical area. Importantly, in the present study, stress not only occurred at the cervical portion of the distal implants but also along their bodies, extending to their middle and apical thirds. To minimize the stress on the implants closest to the cantilever, occlusion was reduced by applying less occlusal torque to that area than in the areas closest to the implant support. The compressive forces on the cantilever might result in an intensity that is two- to threefold greater than the load applied to that segment.\(^{22}\) The effect of cantilever in stress distribution over implants began to be studied with the “all-on-four” concept development.\(^{11}\) In 2010, Naconecy et al\(^{20}\) found considerable stress at the distal implants and those closest to the cantilever. Furthermore, this stress increased when the implants were
placed straight or parallel to the tilted distal implants. The load increase also generated stress on the central implant, which mostly affected its apical region. This result increased the stress at the central implant and the implants closest to the cantilever point, the occurrence of compression forces in the implants closest to the cantilever, and the traction and compression forces in the most distal implants. The present study compared the mandibles with 10-, 13-, and 15-mm implants and found that the stress was greatest in the central and distal implants of the model that contained 10-mm implants. The 10-mm implants were exposed to a greater overload than the 13- and 15-mm implants. The stress generated by occlusal loading, which dissipates through the prosthesis when it passes through the implants and around their surface (in contact with the resin), is transferred to the shortest implants with greater intensity. This effect might result in greater stress, deformation, and eventual bone loss.

Previous studies assessed the success rate of implants and the effects on the bone surrounding them as a function of implant length and diameter. With respect to implant length, most authors have found correlations between shorter lengths and lower survival rates; however, other studies have not found any relationship between marginal bone loss and the number or length of implants. Yet other studies found that implant length alone does not influence prognosis but that the placement area must be taken into account because the maxilla is associated with poorer outcomes than is the mandible. According to some studies, 13-mm implants exhibit higher success rates than do 10-mm implants; furthermore, other factors might influence success rates (eg, parafunctional habits, the crown/implant ratio, inclination, implant distribution, and cantilever length). The aforementioned studies reinforce the findings of the present study, which found that 15-mm implants were associated with better distribution of force per unit area than the 13-mm implants. The stress generated by occlusal loading, which dissipates through the prosthesis when it passes through the implants and around their surface (in contact with the resin), is transferred to the shortest implants with greater intensity. This effect might result in greater stress, deformation, and eventual bone loss.

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REFERENCES


FIGURE 3. Lateral photographs of the photoelastic models across all three implant lengths and load levels: (a) MD 10 = right side; (b) MD 10 = left side; (c) MD 13 = right side; (d) MD 13 = left side; (e) MD 15 = right side; (f) MD 15 = left side.


