Photoelastic Analysis on Different Retention Methods of Implant-Supported Prosthesis

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The aim of this study was to evaluate the stress distribution of different retention systems (screwed, cemented, and mixed) in 5-unit implant-supported fixed partial dentures through the photoelasticity method. Twenty standardized titanium suprastructures were manufactured, of which 5 were screw retained, 5 were cement retained, and 10 were mixed (with an alternating sequence of abutments), each supported by 5 external hexagon (4.0 mm × 11.5 mm) implants. A circular polariscope was used, and an axial compressive load of 100 N was applied on a universal testing machine. The results were photographed and qualitatively analyzed. We observed the formation of isochromatic fringes as a result of the stresses generated around the implant after installation of the different suprastructures and after the application of a compressive axial load of 100 N. We conclude that a lack of passive adaptation was observed in all suprastructures with the formation of low-magnitude stress in some implants. When cemented and mixed suprastructures were subjected to a compressive load, they displayed lower levels of stress distribution and lower intensity fringes compared to the screwed prosthesis.

Key Words: dental implants, suprastructure, stress, prosthesis

INTRODUCTION

The biomechanical behavior of prosthetic dental implants, especially related to the passive adaptation and the stress generation on the implant and surrounding tissues, has received attention from several researchers.¹,² The choice between screwed or cemented prosthesis retention has strongly influenced the final treatment planning, because it directly affects the force transmitted to the components and the bone-implant interface.³,⁴ The dental literature is plenty of papers that state the superiority of one technique over the other.⁵,⁶ The main advantage of screwed prostheses is related to their reversibility. Aesthetics and occlusion are highlighted as advantages of cemented retention, in addition to the simplicity of manufacturing and reduced component costs.⁷,⁸ Photoelastic analysis has been widely used in dentistry to study the distribution of stresses around partially removable⁹ or fixed¹⁰ prosthesis and osseointegrated implants.¹¹,¹² This technique enables a 2-dimensional view, providing information on the magnitude and concentration of stress.¹³ Experimental papers evaluated different implant designs,¹⁴,¹⁵ and others studies compared the screwed and cemented retention systems through photoelasticity. However, despite the great number of researches focusing on stress distribution with different prosthetic retention systems, there is no study mixing different types of prosthetic retention systems.¹⁶,¹⁷ Programmed stress tests were used in this study to determine the transfer of stress by screwed, cemented, and mixed suprastructures to implants with the goal of evaluating the passivity and stress distribution of fixed partial prostheses, on each type of suprastructure.

Hypothesis: Do the mixed prostheses have different stress distributions compared the screwed and cemented prosthetic retention systems? The aim of this study was to evaluate the stress distribution of different retention systems (screwed, cemented, and mixed) in 5-unit implant-supported fixed partial dentures through photoelasticity.

MATERIALS AND METHODS

A preliminary plaster model was made that measured 25 mm high, 35 mm long, and 12 mm thick. A motor coupled to a parallelometer was used to drill 5 holes that were 15 mm deep with a 4.35-mm drill (Conexão Sistema de Prótese Ltda, São Paulo, Brazil). Five external hex implant analogs (Conexão Sistema de Prótese Ltda, São Paulo, Brazil) were
inserted into these holes with cyanoacrylate and type IV plaster. The analogs were parallel and equidistant, with a 7-mm center-to-center separation distance. A layer of colorless enamel (Colorama, Cosba Cosmetics, São Paulo, Brazil) was applied to the plaster, which provided a smooth and polished surface. This construction was then used as a final working model and served as the standard for preparing the photoelastic model. To obtain the photoelastic model, the plaster model was duplicated using photoelastic resin PL-2 (Measurement Group Inc, Raleigh, NC) in a beaker by mixing resin and hardener at a 1:1 ratio (50 mL each) and manipulated using a plastic tube. A lid was made with pink number 07 wax (Epoxiglas, Diadema, Brazil). Then, the plaster model with analogs was connected to the molding components and fastened to the wax lid inside of a plastic tube, such that the model was fixed (i.e., did not move) inside the tube. Laboratory silicone for model duplication (Silicone Master, Talladium Inc, Valencia, Calif) was poured inside each tube until the silicone completely filled the plaster model and the components connected to the analog moldings. After 2 hours (the silicone setting time), the wax lid was removed from the plastic tube, and the plaster model was removed from the silicone mold.

After obtaining the mold, five external hex implants, each with a diameter of 3.75 mm and a height of 11.5 mm (Conexão Sistema de Prótese Ltda, São Paulo, Brazil), were set. Then, the PL-2 photoelastic resin (Measurement Group Inc, Culver City, Calif) was stirred with a glass rod in a circular motion for 5 minutes to obtain a mixture with a homogenous color. The container was then placed in a vacuum chamber (Fast Vac, JB, Brazil) for 30 minutes to eliminate air bubbles for complete polymerization of the photoelastic resin. After 30 minutes and allowed to rest for 48 hours in a cool, ventilated area for complete polymerization of the photoelastic resin.

The plaster model was used to make 20 suprastructures, ie, 5 in each of the following groups: (1) screwed prosthesis, (2) cemented prosthesis, (3) mixed prosthesis 1, and (4) mixed prosthesis 2.

**Screwed prosthesis**

To prepare the screwed prostheses, 5 estheticone abutments (Conexão Sistema de Prótese Ltda, São Paulo, Brazil) were positioned on the analogs attached to the plaster model. These abutments had a brace height of 1 mm and were fastened by applying a torque of 20 Ncm using a manual torque wrench. The abutment suprastructure was waxed, thereby maintaining the insertion axis of the screws. The suprastructure was then cast and polished with grade 1 titanium (Tritan, Dentaurum, Ispringen, Germany) according to the standard methodology. This suprastructure was separated into 4 sections using a carborundum disc and rejoined with laser welding.

**Cemented prosthesis**

To prepare the cemented prostheses, 5 straight abutments (Conexão Sistema de Prótese Ltda, São Paulo, Brazil) and estheticone abutments (Conexão Sistema de Prótese Ltda, São Paulo, Brazil) were positioned on the analogs, which were attached to the plaster model with screw fittings. Three straight abutments with a brace height of 1 mm and 2 estheticone abutments with a brace height of 2 mm were applied with a torque of 20 Ncm using a manual torque wrench. The straight abutments were waxed, thereby preserving the insertion axis of the screws. The suprastructure was then cast and polished with grade 1 titanium according to the standard methodology. Then, the castings were welded to the titanium copings of the estheticone abutments, which formed a suprastructure that began and ended with straight abutments.

**Mixed prosthesis 1**

To prepare the type 1 mixed prostheses, alternating straight abutments (Conexão Sistema de Prótese Ltda, São Paulo, Brazil) and estheticone abutments (Conexão Sistema de Prótese Ltda, São Paulo, Brazil) were positioned on the analogs, which were attached to the plaster model with screw fittings. Three straight abutments with a brace height of 1 mm and 2 estheticone abutments, which formed a suprastructure that began and ended with straight abutments.

**Mixed prosthesis 2**

To prepare the type 2 mixed prostheses, the same methodology was applied as for the type 1 mixed prostheses, but the number and sequence of the abutments was changed. Three estheticone abutments with a brace height of 1 mm and 2 straight abutments with a brace height of 2 mm were fitted with a torque of 20 Ncm using a manual torque wrench. The straight abutments were waxed, thereby preserving the insertion axis of the screws, which formed a suprastructure that began and ended with estheticone abutments. The alternative of changing the type and amount of abutment would be to check the influence of the stress distribution. The manufactured mixed suprastructure began and ended with estheticone abutments. Internal adjustments were made to the cemented and mixed (type 1 and 2) suprastructure using silicone fluid (Oranwash L, Zermack, Rovigo, Italy) and a high-speed carbide bur (Extra Torque 605 C, Kavo, Biberach, Germany) to facilitate the flow of cement and obtain a better prosthetic fitting.

Before installation of the abutments, an initial photoelastic assessment of the models was made by placing the models in a container (Campestre, São B. Campo, Brazil) filled with mineral oil to improve the sharpness of the images obtained with a circular polariscope. This device is capable of providing a dark field using polarized lens with parallel axis. Thus, it is possible to observe the isochromatic fringes, which have colorful patterns and show the stress intensity. Isocline fringes are also visible, which are dark lines superimposed on the colored fringes and...
represent the direction of the stress. After this analysis, the model was considered free of residual stresses and ready to begin testing. To tighten the abutment screws, a torque wrench (Conexão Sistema de Prótese Ltda, São Paulo, Brazil) was used by following the manufacturer’s recommendations. A torque of 10 Ncm was applied to the screws copings, as recommended by the manufacturer. In the cemented and mixed (type 1 and 2) suprastructure, the temporary cement Temp Bond NE (Kerr Corporation, Orange, Calif) was used on the straight abutments because it allows the removal of the structures when necessary without changing the position of the abutments. Through the photoelastic analysis, it was possible to visualize the stresses at the resin-implant interface at two moments: (1) during the installation of the suprastructures, and (2) after applying a vertical compressive load of 100 N on a universal testing machine (Mecmesin, Slinford, UK) at a central point of the suprastructures. Images were recorded with a digital camcorder, FD-717 (Sony, Foster City, Calif). The selected images were qualitatively assessed in terms of the direction of propagation and the intensity of the stress. A greater number of fringes indicate a greater magnitude of stress, and fringes that are closer to each other indicate a greater concentration of stress on each region of the test block.18

After each test, the models underwent a heat treatment to eliminate any residual stress, which consisted of immersion in water at 55°C for 5 minutes.19

RESULTS

In the present study, we observed the formation of isochromatic fringes resulting from stresses generated around the implants after installation of different suprastructures and after applying an axial load of 100 N. Among the images obtained, one from each structure group was selected based on image quality criteria. All images were evaluated by the same operator.

Figure 1a to 1d show the lower number fringes (black color) generated in the model after the installation of the suprastructure. In all of the suprastructure, generalized stresses were observed that dissipated from the apex to the region of the middle third of some implants, which characterized them as lacking passivity.

After applying a compressive load of 100 N at the midpoint
of the suprastructure (Figure 2a to 2d), there was an increase in the number of fringes that showed the presence of tensions in the photoelastic model (red and green colors). Considering the number of fringes of high intensity, the largest area of stress concentration between the implants occurred in the apical and cervical regions, with the greatest intensity in the screwed suprastructure, followed by the mixed 2, mixed 1 and cemented suprastructure in descending order.

**DISCUSSION**

Most studies of the biomechanical behavior of implants under occlusal loads are performed using finite element analysis or occlusal testing, where it is possible to quantify the generation of stresses transferred to the implants. Adding to these works, photoelastic analysis is proposed by the present study as a methodology to qualify how the transmission of stress occurs in partially fixed prosthetic implants. Photoelastic analysis permitted a comparison of the distribution of stresses induced by different partially fixed prosthetics (screwed, cemented, and mixed) with 5 elements in regions adjacent to the implants during installation and after applying a vertical compressive load of 100 N. The photoelastic method demonstrated the advantage of providing direct visual information about the pattern of stresses that occurred throughout the model after applying loads, which allowed the magnitude of the stress to be located and qualified.

Although photoelastic models are used in dentistry to assess stress, they are limited with regard to predicting biological responses to specific loads because this technique does not quantify the stress thresholds of the various bone types. The methods of retention, such as cement, screws and combinations thereof, provide discrete stress levels at the time of suprastructure installation, even after being internally adjusted with silicone fluid. The 4 types of implanted fixed partial prosthetics did not show a passive fit and produced stresses of low magnitude in some implants which was likely related to laboratory inaccuracies, the fabrication model and the molds. The lack of a passive fit of the prostheses generates significant stresses on the implants. According to some authors, a complete passive suprastructure is not possible through laboratory, clinical, and conventional procedures. The methods for assessing fit often do not show inaccuracies, and a more sensitive technique for measuring stresses should be used through the application of technological resources to obtain a clinically acceptable level of passivity that does not cause any aesthetic, biological, or functional problems for the patient.

In this study, the greatest intensity and concentration of stresses were observed in the apical and cervical regions, with the greatest intensity in the screwed suprastructure, followed by the mixed 2, mixed 1 and cemented suprastructure in descending order.

**FIGURE 2.** Demonstration of the results observed after application of a 100-N compressive load. (a) Load application on screwed suprastructures; (b) load application on cemented suprastructures; (c) application of mixed load 1; and (d) application of mixed load 2.
tension after the application of compressive load of 100 Ncm was observed in the screwed suprastructure, followed by the mixed 2, mixed 1, and cemented, respectively. We believe that the presence of cement may have been a favorable factor in lower dissipation of tension between the cemented prostheses and mixed 2, since the presence of cement absorbs an amount of load and stress that would be transferred to the implants.

The splinting of fixed partial prosthetics is another interesting point in this study because the stress distribution occurred in all implants but not equally, probably due to the different retention systems. These findings corroborates another literature reports about stress distribution in prostheses subjected to occlusal forces, where tensions are higher in screwed prostheses and smaller in the cemented ones, probably owing to the hypotheses mentioned above.

Comparing the mixed suprastructures it was observed a higher concentration of tension in the cervical and apical region in suprastructure mixed 2, probably related to the amount of screwed abutments. Although we do not know precisely the levels of loads that may be harmful to osseointegration, it is recommended careful control of axial or extra-axial loads through the prosthetic planning. However, clinically, the bone is strongest under compressive forces, weaker under tensile loads, and even weaker yet in shear loads.

The combined retention between the cement and screw systems generated less stress than the screwed prosthesis, making it a good rehabilitative choice. The use of cement also provided a degree of tolerance to poor adjustment, retrievability, and the ease of repair with the screw.

The mixed and cemented prostheses displayed lower levels of stress distribution and a lower fringe intensity than the screwed implants when subjected to compressive loads in both the cervical and apical regions of the implants, but it was not clear whether these differences were related to the retention system.

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