Stress Distribution after Installation of Fixed Frameworks with Marginal Gaps over Angled and Parallel Implants: A Photoelastic Analysis

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Purpose: The objective of this work was to compare by photoelastic analysis the stress distribution along a fixed framework placed over angled or parallel implants with different gap values between the framework and one of the implants.

Materials and Methods: Two photoelastic models were created: (i) with parallel implants; (ii) with a 30° angled central implant. In both cases, three implants were used, and CP titanium frameworks were constructed with commercial components. A plane polariscope was used to observe the photoelastic fringes generated after initial framework assembly, and also when an axial load of 100 N was applied over the central implant. For both models, stress analysis was conducted on well-fitting frameworks and on another with a 150 μm vertical gap between the framework and the central implant.

Results: The photoelastic analysis indicated that in the model with parallel implants, stress distribution followed the implant axis, and in the model with an angled implant, a higher and nonhomogeneous stress concentration was observed around the apical region of the lateral implants. The placement of an ill-fitting framework resulted in increased preload stress patterns.

Conclusion: Stresses were generated after screw tightening of the frameworks, increasing when a load was applied and when a vertical gap was present. Angled implants resulted in oblique stress patterns, which were not transferred with homogeneity to the polymeric model.

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INDEX WORDS: dental implant, fixed prosthesis, framework, photoelasticity, implant-supported prosthesis

THE FABRICATION of an ill-fitting prosthesis can occur, even with careful technique, since clinical and laboratory techniques are subject to many variables.[1] Placement of an ill-fitting screw-retained, implant-supported prosthesis can cause the deflection of implants, components, and of the bone and the framework while the components are approaching each other.[1-4] Deflection generates preloads, which are associated with displacements and internal stress in structures, and may act constantly in the bone because of the anquilotic nature of osseointegration.[5,6] Clinical consequences related to the placement of misfitted implant-supported prostheses may include pain, discomfort, screw loosening, and fracture of implants, screws, or components.[7] Therefore, a passive fit is considered essential for homogeneous load distribution along all implant components and the bone and, consequently, for the longevity of rehabilitations.[2,5]

O'Mahony stated that, in order to obtain improved biomechanical results, implant placement should be parallel, so loads are axially transferred to the implants;[8] however, due to anatomic limitations and esthetics, implants may be placed with angulations.[9]

It is also known that oblique forces are generated at the cervical portion of angled implants,[10] which can more easily lead to bone resorption and

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component fracture.[11] According to Canay et al,[12] oblique forces result in compressive stress at the bone crest, which is five times greater than the induced stress by axially-loaded implants.

The photoelastic method allows a direct observation of stress distribution in structures, based on the ability of certain transparent materials to exhibit color patterns, called isochromatic fringes, when stressed and observed under polarized light.[5,13]

The objective of this study was to observe stress intensity and distribution along an experimental model with well-fitted and misfitted prostheses over angled or parallel implants.

Materials and Methods

Two photoelastic models were fabricated in this study. To obtain these photoelastic models, three holes, 8.5 mm away from each other, were drilled in a 30-mm high, 75-mm long, 12-mm wide gypsum cast. The axis of the central hole was slightly off the plane containing the axis of the other two holes. Three implant analogs (013020, Conexão, São Paulo, SP, Brazil) were placed in the holes, as indicated in Figure 1A, and impression copings (025020, Conexão) were later positioned over the analogs (Fig 1B). The set was immersed in a laboratory silicone (Silibor, Clássico, São Paulo, SP, Brazil) and, after polymerization, the gypsum cast and the impression copings were separated from the silicone (Fig 1C). Three dental implants, with dimensions of 3.75 mm × 10 mm (517710, Conexão), previously connected to conical abutments (022023, Conexão), were attached to the impression abutments retained in silicone (Fig 1D). Finally, a bone simulator liquid photoelastic resin (PL-2 Liquid Plastic, Measurements Group Inc., Raleigh, NC) was placed inside the silicone cavity,[5] to provide a photoelastic model with parallel implants (Model P). A second model (Model A) was similarly obtained, except for the central impression coping, which was attached to an implant connected to a 30° angled abutment (033023, Conexão). Figure 2 presents a photograph of the photoelastic Models P (left) and A (right).

One metallic framework was manufactured for each resin model, by using titanium cylindrical components (105004, Conexão), which were laser-soldered (Desktop, Dentaurum, Baasel, Germany) to the 3-mm diameter titanium bars (400304, Conexão) (Fig 1E). The two frameworks initially built were well adapted, with the maximum distance between the implants and the framework not exceeding 10 μm.[11] Misfit measurements were conducted using an optical microscope (Toolmaker Microscope, Mitutoyo, Tokyo, Japan), magnification 170×.

Models A and P in the well-adapted condition were submitted to the photoelastic analysis at three moments: (i) before test, (ii) when frameworks were placed, and (iii) after applying a load of 100 N. On a second step, a 20 N cm torque-control (Lifecore Biomedical Inc, Chasca, MN) was used to attach the framework to the implants—as recommended by the manufacturer (Conexão). The 100 N load,[14] applied to the central implant (third step), was obtained through calibrated weights.

Prior to each of these photoelastic analyses, the polymeric models were kept at 50°C for 1 hour to relax the residual stress generated during model fabrication or testing. This procedure did not result in any apparent harm or distortion of the resin, which has a maximum working temperature of 204°C, according to the manufacturer.

During the photoelastic analysis, the model remained immersed in mineral oil, to minimize light refraction.[15] A plane polariscope was used, instead of a circular polariscope,[5] so the stress contours showed dark fringes, known as isoclinic fringes. Results were registered using a high-resolution digital photographic camera (Mavica FD 97, Sony, Oradell, NJ), and during this qualitative evaluation, it was considered that: (1) the larger the number of fringes, the higher the stress magnitude; and (2) the closer the fringes to each other, the higher the stress concentration.[16]

After the photoelastic analyses of the well-adapted frameworks, these frameworks were sectioned at the soldered titanium bars to separate the central portion of the framework. New soldering procedures, one for Model A and another for Model P, were then conducted in the frameworks. In this new soldering procedure, the titanium cylinders were placed over the implants, but during the attachment with a torque of 20 N cm, a 150 μm spark plug gap gauge (Meissner, Helmstedt, Germany) was positioned between the central abutment and the framework. After the removal of the spacer, a 150 μm gap was generated at the central implant.[17] The spacer remained in position during laser soldering (Desktop).

The procedure followed by the photoelastic analysis of misfitted frameworks was the same as that adopted for the well-adjusted ones.

Results

Figures 3A and 4A indicate that a torque of 20 N cm (recommended by the manufacturer) applied to initial attachment of the frameworks led to internal stress in the models. In the case of Model P, the stress was located around the cervical portion of all implants (Fig 3A), and in Model A this stress was located around the cervical portion of the

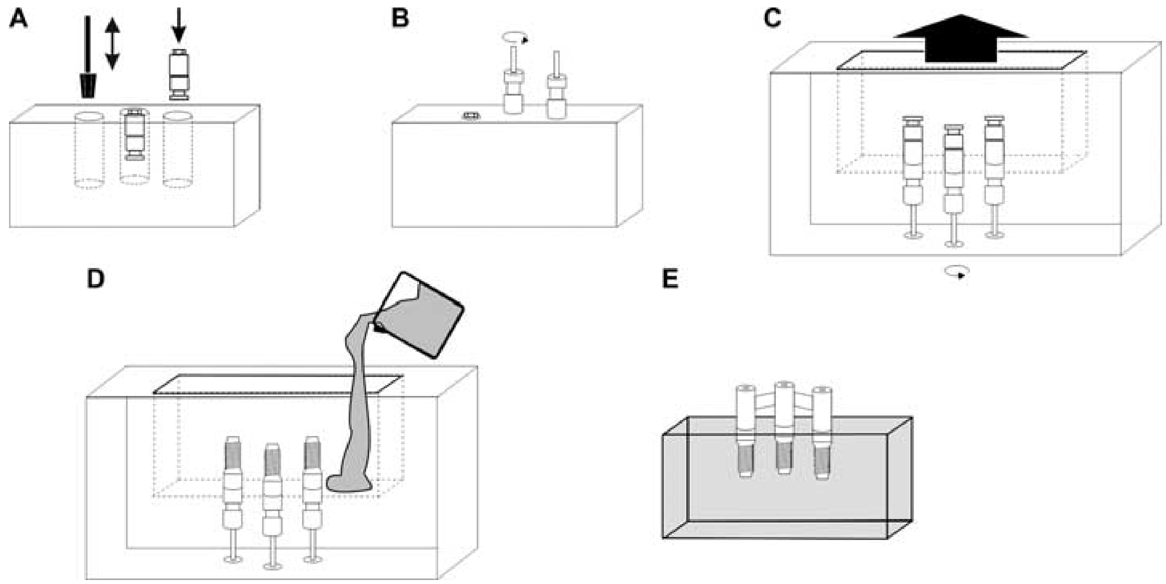

Figure 1. Method used to fabricate the photoelastic models: *(A)* holes made in a gypsum cast and analog positioning; *(B)* impression copings installed; *(C)* impression; *(D)* implants connected to conical abutments positioned, pouring the photoelastic resin; *(E)* manufacture of a metallic framework.

central angled implant and around the implant closer to the bottom of the central angled implant (Fig 4A).

With the application of a 100 N load, stress concentration was noted at the apical region of implants. In Model P, it was possible to observe a higher stress concentration at the apical portion of the central implant (Fig 3B), and in Model A, the stress was concentrated at the apex of the implant closer to the angled implant (Fig 4B).

When Model P was assembled with a 150 μm marginal misfit, the preload stress observed around the lateral implants (Fig 5A) increased compared with that of the well-adapted frameworks. In the misfitted Model A, the preloads were transferred to the body and the cervical regions of the angled implant and to regions around the apices of the lateral implants (Fig 6A). The 100 N load applied to misfitted frameworks did not alter considerably the fringe patterns in Model P (Fig 5B), but an increase in fringe density was observed in Model A (Fig 6B).

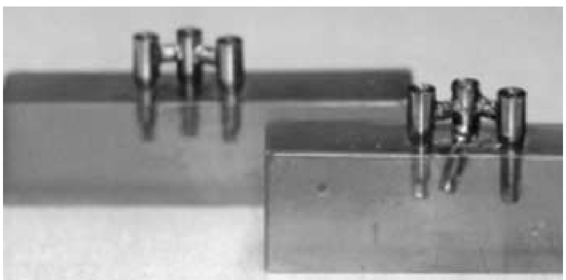

Figure 2. Photoelastic polymeric models used in this study. Implants in Model P had parallel axes (left). The central implant in Model A was connected to an angled abutment (right).

Discussion

The photoelastic fringes observed in this work provide an idea of how the regions around the implants were stressed by the presence of an angled implant or by the presence of a gap between the implants and the framework.

The well-fitting photoelastic model analyzed in this study presented low fringe density after screw tightening with a torque of 20 N cm (Figs 3A and 4A); however, when the ill-fitting frameworks received a 20 N cm torque, the fringe patterns showed that the photoelastic resin was evidently stressed (Figs 5A and 6A).

Jemt[17] suggested that clinically, the maximum acceptable level of misfit would correspond to half the distance between gold screw threads (150 μm). According to the mechanical theory previously described by Binon et al,[3] the screw tightening of

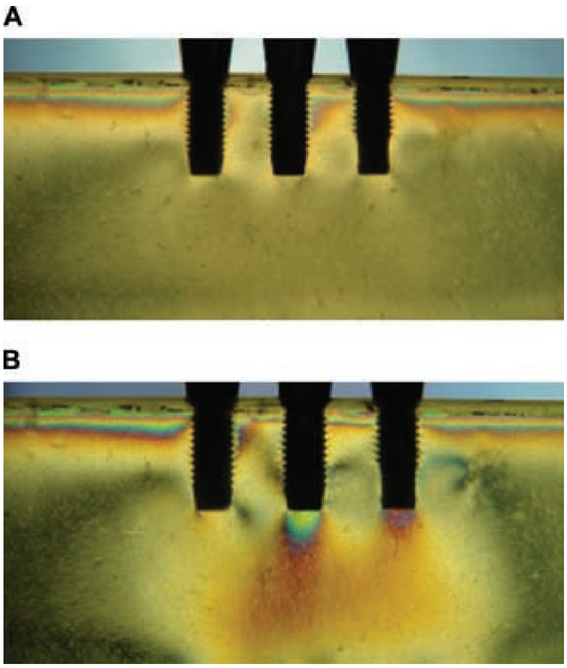

Figure 3. Photoelastic model with parallel implants and well-fitted framework: *(A)* after screw tightening with 20 Ncm torque and *(B)* after 100 N axial load.

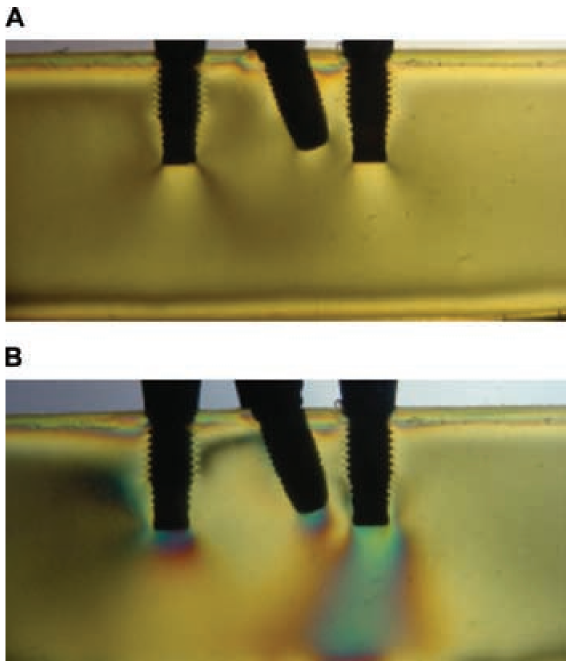

Figure 4. Photoelastic model with angled central implant and well-fitted framework: *(A)* after screw tightening with 20 N cm torque and *(B)* after 100 N axial load.

an ill-fitting framework results in a deflection in the framework and in the components. Jemt and Lekholm[4] used a 3D photogrammetric technique to observe that, in rabbits, the installation of a 1-mm misfitted framework over three implants generated a complex and inconsistent deformation pattern in the bone. In that case, it was possible to observe a rotation of the entire framework, which was forced 150 μm towards the bone, along with a 50–200 μm displacement of the misfitted implant of the framework. Certainly, higher stresses were induced as the implant, together with the bone, approached the framework. In this work, the stress patterns observed in the models with misfitted frameworks (Figs 5A and 6A) indicated higher stresses on the side of the lateral implants, and to the right of the central implant. Figure 7 presents a scheme in which displacements were exaggerated to indicate how the framework displacement, induced by the application of loads and/or by screw fastening, results in the tendency of rotation in the lateral and central implants.

Pietrabissa et al[1] stated that, for well-fitted prostheses, preloads among components do not significantly affect the stress due to mastication; however, in the present study, the application of a 100 N load proved to increase considerably the stress in the regions with preloads (Figs 3 and 4). In these cases, the axial loads applied to parallel implants (Model P) were mainly transferred to the apical region of the implants (Fig 3B), a fact that is in agreement with the observations of O'Mahony et al.[8] It was also noticed that loading of the well-fitted Model A resulted in stress concentrations at the apical region of implants, mainly at the implant closer to the apex of the central implant (Fig 4B).

When loads were applied to the screw-tightened misfitted frameworks, the stress behavior was considerably different from those without a gap. An axial load transfer was not seen; instead, loads remained concentrated around the implants, mainly the central one, where the gap was located. Besides, the increase in stress magnitude induced by the 100 N load was minimal (Figs 5 and 6), which indicates that frame rotation caused by the 100 N load was not evident compared with that obtained due to the presence of the 150 μm gap. This nonaxial stress distribution provides further evidence that the biomechanical behavior

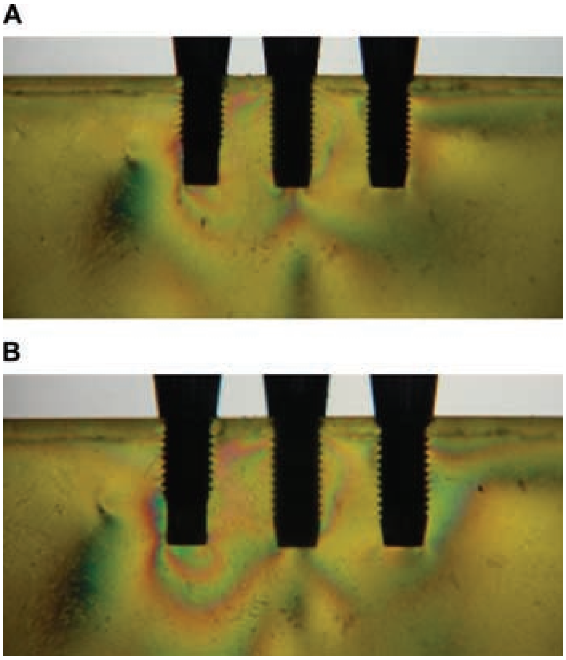

Figure 5. Photoelastic model with parallel implants and 150 μm misfitted framework: *(A)* after screw tightening with 20 Ncm torque and *(B)* after 100 N axial load.

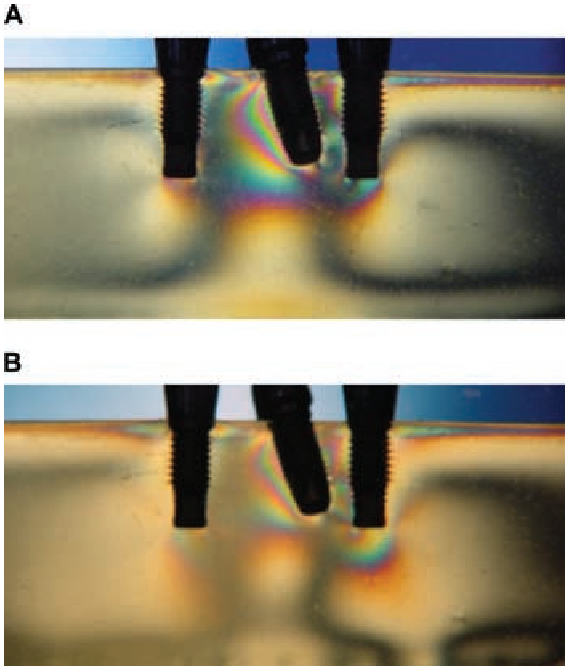

Figure 6. Photoelastic model with angled central implant and 150 μm misfitted framework: *(A)* after screw tightening with 20 Ncm torque and *(B)* after 100 N axial load.

of a misfitted prosthesis is different from that of a well-fitted prosthesis.

The results of this work may not be considered in complete agreement with the literature, since studies indicate that higher stresses should be generated at the cervical region of angled implants.[8,10,12] One explanation for this difference may be the lack of morphology and reproduction of the cortical and cancellous bone by the photoelastic resin models, since cortical bone is stiffer and may prevent most of the load transfer to the medullar region.[9]

The results of this study suggest that a framework passive fit is one of the main factors for the longevity of oral implant rehabilitations; however, it is important to observe that, in spite of the apparent increase in stresses, angled implants are often used in some clinical situations,[9] with good clinical outcomes. Therefore, although the results of this work are insufficient to counter-indicate angled implants, they indicate that parallelism among implants is desirable.

Further research in this field could assess some procedures that would, theoretically, reduce the stress in angled implants, improving the framework design and the selection of more favorable materials. Results may be clinically more relevant with photoelastic models with cortical and medullar bone-like resins.

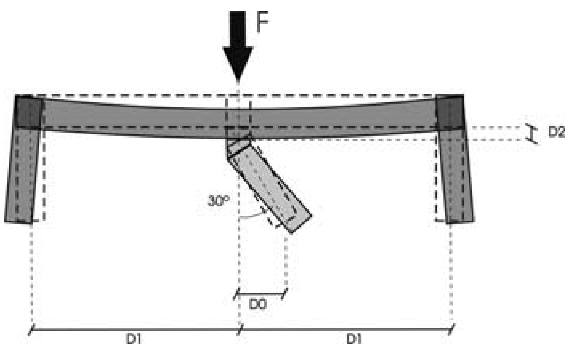

Figure 7. The displacements induced by screw fastening and/or the application of an external vertical load were exaggerated to show the implant rotation tendency. *F*, axial load; D_0, distance between implant long axis and implant extremity; D_1, distance between implants; D_2, marginal gap between the framework and the abutment.

Conclusions

The photoelastic method was used to qualitatively evaluate the stress generated when axial loads were applied to a well-fitting framework and to another with a 150 μm vertical misfit, over parallel and angled implants. On the basis of the results, it was possible to conclude:

1. The presence of fringe patterns indicated that, upon screw tightening, stresses were induced in the resin models for both well-fitting and ill-fitting frameworks.
2. The placement of an ill-fitting framework resulted in increased preload stress patterns.
3. The initial preload stress patterns increased when the axial load increased.
4. Parallel implants resulted in stress gradients, mainly parallel to implant axes, and angled implants resulted in oblique stress patterns, which were not transferred with homogeneity to the polymeric model.
5. An ill-fitting framework concentrates preload and oclusal load stresses around the implant laterally, instead of transferring forces axially.

Acknowledgments

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