Photoelastic Analysis of Stress Distribution With Different Implant Systems

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The aim of this study was to evaluate stress distribution with different implant systems through photoelasticity. Five models were fabricated with photoelastic resin PL-2. Each model was composed of a block of photoelastic resin (10 × 40 × 45 mm) with an implant and a healing abutment: model 1, internal hexagon implant (4.0 × 10 mm; Conect AR, Conexão, São Paulo, Brazil); model 2, Morse taper/interial octagon implant (4.1 × 10 mm; Standard, Straumann ITI, Andover, Mass); model 3, Morse taper implant (4.0 × 10 mm; AR Morse, Conexão); model 4, locking taper implant (4.0 × 11 mm; Bicon, Boston, Mass); model 5, external hexagon implant (4.0 × 10 mm; Master Screw, Conexão). Axial and oblique load (45°) of 150 N were applied by a universal testing machine (EMIC-DL 3000), and a circular polariscope was used to visualize the stress. The results were photographed and analyzed qualitatively using Adobe Photoshop software. For the axial load, the greatest stress concentration was exhibited in the cervical and apical thirds. However, the highest number of isochromatic fringes was observed in the implant apex and in the cervical adjacent to the load direction in all models for the oblique load. Model 2 (Morse taper, internal octagon, Straumann ITI) presented the lowest stress concentration, while model 5 (external hexagon, Master Screw, Conexão) exhibited the greatest stress. It was concluded that Morse taper implants presented a more favorable stress distribution among the test groups. The external hexagon implant showed the highest stress concentration. Oblique load generated the highest stress in all models analyzed.

Key Words: dental implant, implant systems, biomechanics, photoelasticity

INTRODUCTION

A factor that affects rehabilitation with osseointegrated implants is the manner in which stresses are transferred to the surrounding bone, and much will depend on the design of the implant, type of connection implant/abutment, the presence or absence of threads, micro architecture, and chemical composition of the implant surface.1–4 Thus, the aim of the functional designs is to direct the loads through a better distribution of forces, optimizing the function of prostheses supported with implants.5

Actually, there are many implant designs available. The evolution has been by way of incremental changes in size, shape, materials, and surfaces of earlier designs, prompted, at times, by market demands rather than basic science research.1,6 From a bioengineering perspective, an important issue is to design the implant with a geometry that will minimize the peak bone stress caused by standard loading.7

Another factor that affects the distribution of stresses on the implant-bone interface is the connection type; thus research on different methodologies has demonstrated the superiority of the internal connection when compared with the
However, in a prospective study regarding marginal bone loss, it was observed that there was no significant difference between both implant systems (Astra Tech and Branemark), which are external and internal connections; however, the authors observed that the pattern of bone remodeling was different for each system.

The design of the threads also has an important role in the dissipation of stresses. The design of the threads of the implant was evaluated by the finite element method, and it was found that bone density is predicted to increase on the tips of the threads of the implants but to decrease inside the grooves. Threadless implants favor developing a softer bone around their periphery compared with implant systems that have threads, and the overall contour (dimensions and the shape) of an implant affect the bone density redistribution. However, the differences between different implant systems (Ankylos, Bicon, ITI, and Nobel Biocare) were relatively small.

Studies comparing different implant designs showed that internal connection implants were more effective in reducing stress in the bone-implant interface. However, research by means of photoelastic analysis concluded that the designs of external and internal hexagons showed similar patterns of stress distribution and that the implant-abutment mating design is not a decisive factor affecting stress and strain magnitudes in a bone simulant. Bozkaya et al. using the finite element method, evaluated the stress distribution in 5 different implant systems under different load levels. They concluded that, in general, overloading occurs near the superior region of compact bone, in compression, and it is primarily caused by the normal and lateral components of the occlusal load. The authors also determined that the areas of stress concentration varied considerably among the 5 different implant systems evaluated.

Research studies evaluating the biomechanical behavior of implants are numerous, but studies analyzing the stress distribution between different implants systems are sparse. Therefore, the aim of this study was to evaluate the stress distribution of different implant systems using the method of photoelasticity.

**Methods and Materials**

Five models were fabricated with photoelastic resin (PL-2 Vishay, Micro-Measurements Group, Inc, Raleigh, NC). Each model was composed of a block of photoelastic resin (10 × 40 × 45 mm) with an implant and a healing abutment of different systems (Figure 1; Table 1). The photoelastic resin was manipulated in accordance with the manufacturer’s instructions.

Each model was positioned in a circular polariscope, and axial (0°) and oblique (45°) loads of 150 N were applied in fixed points on the occlusal surface of the healing abutment with a Universal testing machine (EMIC-DL 3000, São José dos Pinhais, Paraná, Brazil), which was programmed to transmit the load for a period of 10 seconds. The stress resulting on all areas of the photoelastic model was photographed by a digital camera (Nikon D80, Nikon Corp, Tokyo, Japan) and visualized in a graphic software program (Adobe Photoshop CS3, San Jose, Calif) to be visualized for the purpose of analysis.

The photographic records of the samples were analyzed to determine the stress direction and

<table>
<thead>
<tr>
<th>Model</th>
<th>Implant 4.0 × 10 mm, internal hexagon (Conect AR, Conexão Sistema de Prótese, São Paulo, Brazil), with healing abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Implant 4.1 × 10 mm, Morse taper/internal octagon (Standard, Straumann ITI, Andover, Mass), with healing abutment</td>
</tr>
<tr>
<td>2</td>
<td>Implant 4.0 × 10 mm, Morse taper (AR Morse, Conexão Sistema de Prótese), with healing abutment</td>
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<tr>
<td>3</td>
<td>Implant 4.0 × 11 mm, locking taper (Bicon, Boston, Mass), with healing abutment</td>
</tr>
<tr>
<td>4</td>
<td>Implant 4.0 × 10 mm, external hexagon (Master Screw, Conexão Sistema de Prótese Ltda), with healing abutment</td>
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intensity according to the qualitative analysis of Caputo and Standlee\textsuperscript{22} that is used in many studies.\textsuperscript{18,20,23} This analysis established that (1) the higher the number of fringes, the greater the stress, and (2) the closer the fringes, the greater the stress concentration.\textsuperscript{22}

**Results**

The analysis was divided according to the number of fringes of high intensity and the area of stress concentration (cervical, middle, and apical third). All images were evaluated by the same operator.

**Analysis 1: Regarding the number of fringes of high intensity**

See Tables 2 and 3.

**Analysis 2: Regarding the area of fringes concentration**

**Axial Load**

As shown in Figures 2 through 6, it was observed that the pattern of stress distribution was similar for all models.

**Cervical third.** All models showed areas of stress concentration at the cervical third of the implant, but model 5 showed a greater number of fringes, which corresponds to a higher intensity. Model 2 presented a reduced number of fringes as compared with other models.

According to the number of fringes and the proximity between them, it was observed that there was a greater concentration and intensity of stresses in models 5, 1, 4, 3, and 2, respectively.

**Middle third.** In models 1, 3, 4, and 5, small areas

**Figures 1–6.** Figure 1. Implant systems. Figure 2. Internal hexagon (Conect AR, Conexão), axial load. Figure 3. Morse taper/internal octagon (Straumann ITI), axial load. Figure 4. Morse taper (AR Morse, Conexão), axial load. Figure 5. Locking taper (Bicon), axial load. Figure 6. External hexagon (Master Screw, Conexão), axial load.

<table>
<thead>
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<th>Table 2</th>
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<tr>
<td><strong>Axial load</strong></td>
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<tr>
<td>Model</td>
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<tr>
<td>1</td>
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<tr>
<td>2</td>
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of stress concentration of medium to low intensity were observed around the threads. Model 5 showed fringes closer to each other, corresponding to a greater stress concentration, and model 2 showed an absence of formation of isochromatic fringes.

There was a greater concentration and intensity of stresses in models 5, 4, 3, 1, and 2, respectively.

**Apical third.** Models 1, 3, 4, and 5 showed intensity fringes, and these were observed in greater numbers at the apex. Model 5 presented a greater number of fringes and the highest stress concentration.

In model 2, there were areas of low-intensity stresses in the threads, and the fringes were more spaced.

According to the number and proximity of fringes, the models with higher stress were 5, 1, 4, 3, and 2, respectively.

**Oblique Load**

In Figures 7 through 11 the pattern of stress distribution was similar for all models.

**Cervical third.** In all models, there was formation of isochromatic fringes, corresponding to high stress intensity, located at the top of the implant opposite to the load direction side, and these were located bilaterally only in models 1 and 5.

The fringes were more concentrated in models 1 and 5. According to the number and closeness of the fringes, it was observed that there was a greater concentration and intensity of stresses in models 5, 1, 3, 4, and 2, respectively.

**Middle third.** All models showed high-intensity fringes located opposite to the side of the load direction. On the contralateral side, no tensions were observed. Model 2 presented fringes more widely spaced, corresponding to less concentration of tensions.

**Apical third.** In all models, the largest numbers of fringes, corresponding to high intensity, were located on the apical region of the opposite side of the load direction, and these were more concentrated in model 5.

The highest stress intensity observed according to the number and proximity of fringes occurred in models 5, 1, 3, 2, and 4, respectively.

**DISCUSSION**

In the present study, the 5 implants evaluated showed a similar and symmetrical pattern of stress distribution. This result was unexpected because of the different designs of implants tested. However, Cehrel et al.20 observed the same situation under axial loads, when compared with different implant systems using the method of photoelasticity. The major differences in the distribution of stresses in the models tested were observed at the cervical and apical third, and this probably occurred because of the difference between the connection type, implant design, shape of the threads, and the presence or absence of microthreads in the top of the implant.

Analyzing the models, with axial and oblique loads, it was observed that the Morse taper implants (Straumann, Bicon, and RA Morse) presented the lowest stress concentration at the cervical third. From a biomechanical perspective, the reduction of stress at the cervical level will minimize the chances of saucerization, which is biologically advantageous for the reduction of marginal bone loss and long-term success.1,12,18

The Morse taper implants showed the same magnitude of tension; however, differences over the distribution of stresses were observed, and this can be explained by the different shapes of the threads. The shapes of the thread could influence the type of force transmitted to the surrounding bone (compression, tension, or shear).20 The octagonal internal implant (Straumann) showed more dissipated stress and less concentration at the

| Table 3 |
|---|---|---|
| Model | Description | High-Intensity Fringes |
| 1 | Implant 4.0 × 10 mm, internal hexagon (Conect AR, Conexão Sistema de Prótese, São Paulo, Brazil) | 12 |
| 2 | Implant 4.1 × 10 mm, Morse taper/internal octagon (Standard, Straumann ITI, Andover, Mass) | 10 |
| 3 | Implant 4.0 × 10 mm, Morse taper (AR Morse, Conexão Sistema de Prótese, Ltda) | 10 |
| 4 | Implant 4.0 × 11 mm, locking taper (Bicon, Boston, Mass) | 10 |
| 5 | Implant 4.0 × 10 mm, external hexagon (Master Screw, Conexão Sistema de Prótese Ltda) | 14 |
cervical level, which can be explained by the presence of a smooth surface on top of this implant without threads in the cervical third. In addition, this implant has a thread shape called buttress, and according to some authors,\textsuperscript{15,16} this type of thread better dissipates the loads through compression forces. A Morse taper implant (AR Morse) presents a better stress distribution (between Morse taper implants) because of a threaded format called the v-shape, transmitting axial loads through the combined forces of compression, tension, and shear.\textsuperscript{12} At the cervical level of this implant, there was a better dissipation of the tensions, and this can be explained by the presence of microthreads that produce an increase in the contact surface, minimizing the magnitude of the stresses that are distributed in a homogeneous way.\textsuperscript{24} On the other hand, another study,\textsuperscript{25} using the finite element method, concluded that the presence of cervical implant microthreads increased the stress. In relationship to the Bicon implant at the cervical level, a higher stress concentration was observed, probably because of a reduction in the contact area at the top of the implant. The middle third presented with a higher stress concentration, possibly due to the shape of the threads, called a plateau. Similar findings were observed in a finite element study analyzing the design parameters of osseointegrated implants, where the results showed a higher stress concentration in implants with plateau threads when comparing different types of threads.

Comparatively analyzing the types of connections of different implant systems, the application of oblique loading showed the highest stress concentration at the cervical third for the external hexagonal implant. This is to be expected because the external connection, which has a greater rotational freedom in comparison to the internal connection, theoretically could cause micro move-

\textbf{FIGURES 7–11.} \textbf{FIGURE 7.} Internal hexagon (Conect AR, Conexão), oblique load. \textbf{FIGURE 8.} Morse taper/internal octagon (Straumann ITI), oblique load. \textbf{FIGURE 9.} Morse taper (AR Morse, Conexão), oblique load. \textbf{FIGURE 10.} Locking taper (Bicon), oblique load. \textbf{FIGURE 11.} External hexagon (Master Screw, Conexão), oblique load.
ment and therefore higher stress and consequently resorption at the crest.8–10,20

With the application of oblique load, the models presented higher stress concentration in the top of the opposite side of the load application, which was also verified in other studies by means of photoelastic analysis.18,20 The Morse taper models presented a more favorable stress distribution due to the degree of taper of the internal connection that provides a high tolerance and resistance to lateral forces.8,10

In this qualitative study, stress concentration areas and the intensity of stresses (represented by the order of fringes) were observed, allowing for comparison between different implant systems. However, because of the nature of this study, it was not determined whether these magnitudes would be favorable or unfavorable in the process of bone remodeling. Yet it was possible to determine the areas that concentrated stress in the implant-bone interface, indicating the type of implant that is more favorable with regard to stress distribution in certain areas. The choice of implant system should take into account several factors such as the type of connection, type of prosthesis, and whether the prosthesis is supported by single or multiple implants, and so forth.

**CONCLUSION**

Within the limitations of the methodology used, the following is concluded:

1. Morse taper implants (Straumann, Bicon, and AR Morse) presented more favorable stress distribution among the test groups.
2. The external hexagon implant showed the greatest stress concentration.
3. Oblique load generated greater stress in all models.

**REFERENCES**