Stress Distribution Study Using the Finite Element Method in Three Different Implant-Supported Fixed Complete-Arch Mandibular Prostheses

Luiz Felipe Butzke Coelho, DDS, MS, PhD\(^1\)/Josué Ricardo Broilo, DDS, MS, PhD\(^1\)/
Evandro Afonso Sartori, DDS, MS, PhD\(^1\)/Luiz Oscar Honorato Mariano, DDS, MS, PhD\(^1\)/
Tomás Geremia, DDS, MS, PhD\(^2\)/Leonardo Barcellos, DDS, MS, PhD\(^1\)/Leandro Luis Corso, BEng, MS, PhD\(^3\)/
Rosemary Sadami Arai Shinkai, DDS, MS, PhD\(^4\)/Márcio Lima Grossi, DDS, MS, PhD\(^5\)

**Purpose:** The objective of this study was to assess the stress distribution generated by a simulated loading (100 N) in the area of the cantilever in three different five-implant mandibular protocol prosthesis models. **Materials and Methods:** The finite element analysis was carried out in three-dimensional models simulating: (1) a temporary all-acrylic resin mandibular protocol prosthesis; (2) a metal-acrylic mandibular protocol prosthesis; and (3) a metal-ceramic mandibular protocol prosthesis. **Results:** The all-acrylic model promoted the highest stress values on the implant closest to the cantilever loading point. **Conclusion:** This study supports the need for a metallic bar reinforcement in the denture base. *Int J Prosthodont* 2016;29:299–302. doi: 10.11607/ip.4427

The objective of this research was to evaluate, by three-dimensional (3D) finite element analysis (FEA), the stress distribution in three different five-implant mandibular protocol prosthesis models, when these three undergo a simulated occlusal load of 100 N in the area of the cantilever: (1) model A, temporary all-acrylic resin; (2) model B, metal-acrylic; and (3) model C, metal-ceramic.

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**Materials and Methods**

**Modeling of the External and Internal Portions of the Mandible**

The external 3D modeling of the mandible was acquired from the laser digitization of a natural edentulous mandible in the sagittal, horizontal, and frontal planes (0.01-mm precision) using Digimil 3D (Technodrill). The first 3D model was created using Geomagic Studio version 7.0, and then a continuous model was obtained using Rhinoceros 3D version 3.0.

A tomographic image (70 transversal vertical slices, 1-mm thickness) of the same edentulous mandible was obtained using Helicoidal Tomographic Hispeed CTI System Series 6.3 (GE Healthcare). This image was superimposed over the external mandible model to develop the internal model (Rhinoceros 3D version 3.0).

**Modeling of Implants and Prosthetic Components**

The 3D shapes of implant and prosthetic components were obtained by manual measurements (eg, length, diameter, thread pitch) with magnifying lens and a digital caliper. These dimensions were used for generating digital surfaces (Rhinoceros 3D version 3.0), and then solid shapes were obtained (SolidWorks 2012, SolidWorks).
Stress Distribution in Implant-Supported Fixed Prostheses

Modeling of the Fixed Complete-Arch Mandibular Protocol Prosthesis

The 3D shape of the mandibular protocol prosthesis was obtained via prosthesis wax build-up on a resin mandibular model. A physical model of the mandible was milled in acrylic resin. Next, the implants were drilled and fixed in the predefined sites. Finally, the internal and external structures of the protocol prosthesis were manufactured in acrylic resin and wax.

Modeling of the Internal and External Structures of the Protocol Prosthesis

The 3D shape of the protocol prosthesis was obtained by means of laser digitization (0.01 mm precision) of the wax build-up of the prosthesis and its internal structures in all three planes (Digimill 3D). The 3D model was obtained (Geomatic Studio version 7.0), and these images were superimposed on the external and internal structures of the digitalized protocol prosthesis material (Rhynoceros 3D) generating a 3D solid, which represented the metallic structure covered with the acrylic base.

Obtaining the Finite Element Models

The implants and their components were positioned in the mandible and edited according to the need for posterior solid generation (Rhynoceros 3D) (Fig 1).

Fig 1  The 3D continuous geometric models and the physical models from which they were digitized.
Stress Distribution in the Mandibular Cortical Bone

Model A received more stress in the mandibular cortical bone (52.1 MPa) than model B (39.2 MPa) or C (39.3 MPa) in implants 1, 2, and 3 (combined). On the other hand, models B and C had a slightly higher concentration in implant 1, but lower concentrations in implants 2 and 3 as compared with model A (Table 2).

Stress Distribution in the Implant Bodies

Model B received more stress in the implant bodies (184.2 MPa) than models A (173.0 MPa) and C (163.9 MPa) in implants 1, 2, and 3 (combined). However, model A concentrated more stress in implant 1 than model B or C (Table 2).

### Results and Discussion

The analyses were concentrated on the areas that received the greatest amount of stress (ie, working side or implants 1, 2, and 3) and on the area closest to the loading point (ie, implant 1).1–5

### Table 1  Mechanical Properties of the Materials Used

<table>
<thead>
<tr>
<th>Geometric model</th>
<th>Model of elasticity (MPa)</th>
<th>Poisson coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical bone</td>
<td>13,700</td>
<td>0.30 (16)</td>
</tr>
<tr>
<td>Medullary bone</td>
<td>1,370</td>
<td>0.30 (16)</td>
</tr>
<tr>
<td>Acrylic resin</td>
<td>2,700</td>
<td>0.35 (17)</td>
</tr>
<tr>
<td>Cylindrical implant (3I)</td>
<td>135,000</td>
<td>0.30 (16)</td>
</tr>
<tr>
<td>Ti (ASTM-F67) pillar screws (3I)</td>
<td>114,000</td>
<td>0.30 (16)</td>
</tr>
<tr>
<td>Nickel-chromium alloy internal portion of prosthesis</td>
<td>188,000</td>
<td>0.28 (18)</td>
</tr>
<tr>
<td>Ceramic esthetic lining</td>
<td>68,900</td>
<td>0.28 (17)</td>
</tr>
</tbody>
</table>

### Table 2  Maximum Stress Values for Five Implants and Related Structures Placed in Three Different Mandibular Cantilever Protocol Prosthesis Models Undergoing a 100-N Load in the Area of the Right First Molar

<table>
<thead>
<tr>
<th>Implant position1</th>
<th>Model A</th>
<th>Model B</th>
<th>Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical bone stress (MPa)</td>
<td>24.7 13.7 13.7 5.4 5.4</td>
<td>27.2 6.0 6.0 3.0 3.0</td>
<td>27.3 6.0 6.0 6.0 6.0</td>
</tr>
<tr>
<td>Implant body stress (MPa)</td>
<td>91.6 40.7 40.7 10.2 0.02</td>
<td>87.2 48.5 48.5 19.5 9.8</td>
<td>83.9 37.3 37.3 18.7 9.3</td>
</tr>
<tr>
<td>Abutment stress (MPa)</td>
<td>116.5 90.6 51.8 26.0 13.0</td>
<td>56.4 37.6 18.9 6.4 6.4</td>
<td>41.7 27.9 14.0 9.4 9.4</td>
</tr>
<tr>
<td>Fixation screw stress (MPa)</td>
<td>76.3 49.0 49.0 16.3 8.1</td>
<td>48.3 21.4 21.4 10.7 5.3</td>
<td>35.2 23.4 23.4 11.7 7.8</td>
</tr>
<tr>
<td>Denture base stress (MPa)</td>
<td>30.5 3.3 0.02 0.02 0.02</td>
<td>12.4 8.2 2.7 2.7 0.02</td>
<td>27.6 21.4 6.1 0.02 0.02</td>
</tr>
</tbody>
</table>

1Implant 1 is the closest to the loading point.
2Values were very close to zero at the millesimal value and were rounded to zero.
Model A: temporary all-acrylic; model B: metal-acrylic; model C: metal-ceramic.

The numeric analysis of the finite elements was carried out by simulating a 100-N occlusal loading in the most distal portion of the cantilever (Fig 2) and determining its consequences on both working and balancing sides.
Stress Distribution in the Abutments

Regarding the stress concentration analysis in the abutment screws, model A received twice as much stress (258.9 MPa) as models B (112.9 MPa) and C (83.6 MPa) in implants 1, 2, and 3 (combined). Similarly, model A concentrated twice as much stress in implant 1 as did models B and C (Table 2).

Stress Distribution in the Fixation Screws

With respect to the stress concentration values (Table 2), model A received more stress (174.3 MPa) in the fixation screws than model B (91.1 MPa) or C (82.0 MPa) in implants 1, 2, and 3 (combined). Similarly, model A concentrated more stress in implant 1 than models B and C.

Stress Distribution in the Denture Base

In the stress value analysis (Table 2), model C (55.1 MPa) received more stress in the denture base than models A (33.8 MPa) and B (26.0 MPa) in implants 1, 2, and 3 (combined). However, model A concentrated more stress in implant 1 than models B and C.

Conclusions

The all-acrylic resin model showed the highest stress values compared with the metal-acrylic and metal-ceramic models in the working side and cantilever implants. These results reinforce the need for a metallic bar reinforcement in the acrylic in the denture base.

Acknowledgments

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References