Strain Behavior of Implant-Supported Full-Arch Fixed Dental Prostheses Supported by Four or Five Implants

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Purpose: Strains transferred to the supporting simulated bone structure by implant-supported full-arch fixed dental prostheses (FAFPs) were analyzed by digital image correlation (DIC). Materials and Methods: Polyurethane models were made using 3.75 × 11–mm implants and divided into the following groups with different implant numbers and design: EHS (five implants/external hexagon), MT5 (five implants/internal taper), EH4 (four implants/external hexagon), and MT4 (four implants/internal taper). Both qualitative and quantitative (one-way analysis of variance [ANOVA] statistical comparison) analyses were performed by the DIC method after the application of a 250-N load in the central fossa of the mandibular first molar. Different regions of interest were selected in the polyurethane model for comparison between groups. Results: Compressive strains were found in the cervical region of the models, and tensile strains were found in the apical region of the models. Significant differences were found in the different analyzed regions of interest for the different number of supporting implants and implant designs (P < .05). Conclusion: Groups with five implants showed more regions with less strain concentration compared to groups with four implants, but strain distribution was similar between groups. The different tested implant designs showed similar strain concentration and distribution to the supporting structures. Int J Oral Maxillofac Implants 2022;37:153–158. doi: 10.11607/jomi.9087

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Implant-supported restorations are the current treatment of choice for partial and total rehabilitation procedures due to survival rates of about 90% and 95% in the maxilla and mandible, respectively.1 The early loss of posterior teeth leads to bone resorption over time, which may influence the implant number, position, size, and diameter, as well as dental prosthesis design.2,3 Placing implants in the posterior region of the mandible is challenging due to the presence of the inferior alveolar nerve; the mandibular interforaminal region is therefore selected to avoid highly complex surgical procedures.3

Short implants, bone grafting, transposition of the inferior alveolar nerve,4 and tilted implants are commonly used.5 A 30-degree implant tilting with fewer implants

(All-on-4, Nobel Biocare) is also recommended for selected rehabilitation cases.6,7 The All-on-4 treatment concept could optimize stress distribution by reducing the cantilever extension and increasing the prosthesis support area.8–10 Stresses at the bone-implant interface, implants, and prosthesis components are minimized with a reduced distal extension.11,12 Earlier studies reported comparable long-term survival of fixed dental prostheses supported by four implants and by five or more implants.7,13–15

External hexagon implant connections are widely used and present an antirotational system, reversibility, and compatibility between different implant manufacturers.16 However, external hex connections may lead to bone resorption when subjected to oblique loads due to micromovement at the implant-abutment interface.16,17 Internal tapered connections provide a mechanical interlock between implant and abutment that leads to a more stable interface.18 The intraosseous placement of internal tapered implants provides increased fracture strength, and a slight implant tilting should be corrected with angled abutments.19–22

Digital image correlation (DIC) has been used to calculate surface strain distribution and to analyze the biomechanical behavior of implant-supported restorations.23,24 Opposed to strain gauges, which are limited to measuring the strains within the gauge area, DIC provides a full-field surface strain measurement.24,25 There
is no consensus as to the best implant and prosthesis configuration that provides more optimized strain distribution. This study analyzed different implant-abutment connection designs with different implant number and placement configurations. The tested null hypothesis was that the different implant designs and configurations would not influence the surface strain distribution.

**MATERIALS AND METHODS**

External hexagon (EH) and Morse taper (MT) dental implants were placed in four edentulous mandible polyurethane models (Nacional Ossos, Jaú) for the following groups in the study: EH5 (five external hexagon implants); MT5 (five tapered implants); EH4 (four external hexagon implants); MT4 (four tapered implants). External hexagon implants were placed at bone level, and tapered implants were placed 2 mm intraosseous. All implants were 3.75 × 11 mm (Neodent). The implants in groups with four implants were 15 mm distant from each other, with the two distal implants tilted at 30 degrees relative to the sagittal plane and with the two middle implants parallel to each other in an axial position.6 The implants were placed 10 mm apart in an axial position for the groups with five implants (Figs 1a to 1c).

Prosthetic abutments (Mini conical abutments, Neodent) were screwed to the EH implants with a 20-Ncm torque load, whereas a 32-Ncm and a 15-Ncm torque load were used for the axial and angulated (tilted) abutments for the MT implants. Imression transfer abutments were then screwed to the prosthetic abutments and connected to each other with acrylic resin (Duralay, Reliance Dental Mfg Co; Fig 1d).26 A silicone impression was performed (Fig 1e), and the silicone mold was used to fabricate the polyurethane models—polyol and isocyanate were mixed at 1:1 ratio to obtain a rigid polyurethane material with similar elastic modulus to the bone, as described by Moretti Neto et al27 and Miyashiro et al28 (polyurethane for pouring F16, Axson; Fig 1f). A full-arch fixed dental prosthesis (FAFDP) was then fabricated for each group in the study. A 12-mm distal cantilever was present in the FAFDPs supported by four implants (because of the tilted distal implants), and a 15-mm distal cantilever was present in the FAFDPs supported by five implants.

Implant-supported bars were waxed and duplicated in acrylic resin (Duralay) for each group by using laboratory silicone (Zetalabor, Zhermack). All acrylic resin bars were invested (Heat Shock, Polidental Ind Com Ltda) and cast in CoCr alloy (Fit Cast Cobalto, Talmax). The cast bars were divested, airborne-particle abraded with aluminum oxide, and finished with tungsten drills. All bars showed some misfit with the abutments and were sectioned for conventional welding. Each welded bar was again checked for misfit and showed clinically acceptable fit. The FAFDPs were then fabricated for the groups and screwed to the abutments with a 10-Ncm torque.

DIC was used to analyze the model surface strains transferred by each group. The DIC equipment (Strain-Master, La Vision Inc) included two charge-coupled device (CCD) cameras (Imager Intense, LaVision) with a resolution of 1,039 × 1,395 pixels that were used to capture images of the models under load. Each model surface was painted with a thin layer of white spray paint (Colorgin, Sherwin-Williams Brazil) and with small black spray paint dots that were used by the DIC system to calculate surface strains.23 A 250-N load was applied on the first molar with crosshead speed of 0.5 mm/min.
using a loading device (Biopdi; Fig 2). Images from the models were taken at a 1-Hz frequency until the 250-N load was reached. Specialized software (DaVis 8.1.2, LaVision) was later used to calculate the surface strains. The DIC software (DaVis 8) used the displacement of the black paint dots to calculate the surface horizontal strains (Exx). Four regions of interest were selected on the models’ surface for comparison between groups. The position of the last implant was used as a reference to determine the regions to be analyzed. A 4 × 6-mm region of interest was selected near the distal of the last implant (C1–cervical 1 and A1–apical 1) and another 4 × 6-mm region of interest was selected mesial to the same implant (C2–cervical 2 and A2–apical 2; Fig 3).

Each group was loaded three times (T1, T2, T3) to verify the correct performance of the DIC system. The three measurements were compared to each other to verify the repeatability and reliability of the DIC method and the results found. Groups were compared both quantitatively and qualitatively. Statistical comparison between groups was performed by one-way analysis of variance (ANOVA) test using specialized software (JMP 8.1, SAS Institute).

**RESULTS**

Figure 4 shows the surface strains found for each group (EH5, MT5, EH4, MT4). Compressive strains were found on the cervical region of the models, whereas tensile strains were found near the apical part of the implants. The C1 region of interest showed mostly compressive strains, with significant differences between FAFDPs supported by different prosthetic connections (P < .001) and by four or five implants (P < .001; Table 1). Compressive strains were also found in most of region of interest C2. Significant differences were found between groups with four or five implants and with tapered and external hexagon implants (P < .001). Different prosthetic connections within groups with the same number of implants (four or five implants) were significantly different (P < .05).

Tensile strains were found in most of the A1 region of interest (Fig 4). Significant differences were found between external hexagon and tapered implants when groups with four or five implants were compared (P < .05) (Table 2). Significant differences were also found when groups with four and five implants were compared for...
both external hexagon and tapered implants ($P < .001$). The region of interest A2 also showed mostly tensile strains. Significant differences were found in the number of supporting implants only for the groups with tapered implants ($P < .0001$; Table 2). Significant differences were also found when different prosthetic connections were compared within groups with the same number of supporting implants ($P < .0001$).

### DISCUSSION

The results found in this study support rejection of the tested null hypothesis, since significantly different strain values were found between groups. However, the different groups showed similar strain pattern distribution to the supporting simulated bone structure. Compressive strains were found in the cervical region of the model surface, whereas tensile strains were found in the apical region with increased strain values when five Morse taper implants were used. Strain values were greater in the cervical regions when four implants were used.

Earlier studies showed that optimized stress concentration is found with an increased number of implants. A similar strain distribution between groups with four and five implants was found in the present study, as opposed to an earlier study that found different stress distribution behavior when four or five supporting implants were compared. The difference in results can also be attributed to the material in which the working models were made, since the study carried out by Francetti et al. used steel models whereas this study used polyurethane models. Tilted implants also showed less stress concentration compared to axial implants. A 30-degree implant tilting led to a 17% stress reduction in the supporting bone. Another study found that tilted implants reduced bone stress concentration by 52% and by 47.6% in cortical and cancellous bone, respectively. More inclined implants (30 degrees and 45 degrees) lead to a shorter distal cantilever compared to less inclined implants (0 and 17 degrees), thus leading to less stress concentration in the supporting structures.

The different prosthetic connections (external hexagon and internal taper) tested in this study showed similar strain distribution behavior, which agrees with another study that found the same outcome. However, other studies showed that external hexagon connections are less efficient under oblique loading.
This study found that the external hexagon connection had more compressive strains compared to the internal tapered connection in the distal region of the last implant when five implants were used. This agrees with an earlier finite-element study\(^\text{37}\) that showed higher stress concentration in the cervical region of the distal external hexagon implants compared to distal internal tapered implants. Conversely, another study found that partial prostheses supported by external hexagon implants showed better stress distribution compared to internal tapered implants.\(^\text{38}\) When four implants were used in this study, the external hexagon connection presented higher strain values than the internal tapered connection in the apical region, while the inverse effect was noted in the cervical region, with greater strains in the tapered implants. This difference can be attributed to the implant position related to the bone level and tilting.

The size of the distal cantilever is another source for strain concentration—prosthesis survival rate is higher with a 15-mm or less distal extension, but the number of implants and their distribution also accounts for a successful outcome.\(^\text{39–42}\) However, this study found that the groups with four implants showed higher strain concentration, despite the shorter distal extension. This could be due to the 30-degree tilting of the distal implants and to the higher load on the distal implants when a cantilevered prosthesis is present, irrespective of the total number of implants.\(^\text{3,41}\)

Bone strain values between 4,000 and 25,000 µε are expected to cause microscopic damage to bone structure, and the onset for bone resorption is estimated to begin at 4,200 µε.\(^\text{43–45}\) The microstrain values found in this study are far below the previously reported threshold for bone resorption, but it should be noted that the DIC method analyzes the model surface strains, and those near the implants are expected to be higher. Despite that, the results indicate that four or five implants can be safely indicated for full-arch mandibular restorations. This agrees with an earlier study\(^\text{46}\) that showed that careful implant distribution in the mandibular bone could provide an optimized stress transfer to the supporting implants. It should also be stated that this study applied a 250-N concentrated load in the first molar and that lower and less concentrated loads are expected in a clinical scenario with a properly adjusted opposing occlusion. Although significant differences were found between the connections and models with four or five implants, the stress distribution was similar and within the levels indicated as clinically acceptable. Further clinical studies are suggested to better understand the biomechanical behavior and the long-term success of the different full-arch mandibular rehabilitations and different implant prosthetic connection designs that were tested in this study.

### CONCLUSIONS

Within the limitations of this study and according to the methodology applied, in which an analysis was made on the surfaces of the models, it can be concluded that the groups with five implants showed more regions with less strain concentration compared to groups with four implants, but the strain distribution was similar between groups.

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### REFERENCES


