The Effect of Platform-Switching Implants and Different Abutment Materials on the Stress Distribution of Implant-Supported Restorations

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The purpose of this study was to evaluate the effect of implant platform-switching design and abutment materials on the stress distribution around implants. Implants were fixed in epoxy-resin models restoring posterior missing first molars, representing two main groups according to the implant-abutment connection. Each group was subdivided according to the type of abutment material used (titanium or zirconia). Twenty monolithic fully anatomical zirconia crowns were fabricated. Stress analysis was measured around the implants using strain gauges during the static loading of each implant-supported crown. Data were collected, tabulated, and statistically analyzed. Standard implant-abutment connection groups recorded the highest (statistically significant; P < .05) mean strain values compared to platform-switching connection groups. Abutment materials in both groups recorded statistically nonsignificant (P > .05) mean strain values. The platform-switching concept showed better crestal-bone stress distribution around implant-supported restorations. Abutment materials expressed no statistically significant effect on the stress distribution around implant-supported restorations. Zirconia and titanium abutments could withstand the functional loads developed during physiologic chewing in the molar area.


Crestal bone preservation around osseointegrated implants is an important criterion for their success.1,2 Several biologic and mechanical factors influence bone resorption around the implant, such as bacterial microleakage and concentration of stresses in the cervical region of the implant.3

Biomechanical questions often arise concerning load distribution on implants and bone.4,5 For accuracy of the evaluation and because of the difficulty in standardizing the obtained values for strain measurement in vivo, this study was conducted in vitro.6

In an attempt to improve long-term bone maintenance around implants, an implant-abutment connection referred to as platform-switching has been proposed. The concept refers to the use of a smaller-diameter abutment on a larger-diameter implant platform.7 In this way, the inflammatory infiltrate is contained mainly above the implant platform, and the peri-implant bone is “shielded” from the inflammatory tissue infiltrate.8

Wang et al9 evaluated the implant success rate and marginal bone response of implants with platform-switching and platform-matched abutments. A statistically significant difference in the marginal bone level change was observed between groups, with least

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marginal bone loss in the platform switching group. In 2016, Ekstein et al.\textsuperscript{10} found limited marginal bone loss and a 100% implant survival rate observed over a follow-up period of 14 months. Telleman et al.'s\textsuperscript{11} 5-year results showed implant survival, favorable peri-implant health, minor interproximal bone resorption around platform-matched and platform-switched implants, and no significant difference between the two groups. Abutment-implant diameter mismatch should be ≥ 0.4 mm so as to have a significant influence on crestal bone loss, as concluded by Atieh et al.\textsuperscript{12} in their meta-analysis of studies on platform switching.

The predictability of an esthetic implant outcome was compromised by the gray discoloration of the marginal peri-implant mucosa induced by titanium abutments.\textsuperscript{13} This limitation led to the introduction of zirconia abutments supported by titanium bases, which have excellent strength and biocompatibility compared to titanium alone.\textsuperscript{13} The esthetic benefit of ceramic abutments over metal abutments has been well documented,\textsuperscript{14} but the mechanical performance and stress distribution are still in debate, as mentioned in another study.\textsuperscript{15}

Numerical techniques such as strain gauge analysis have been broadly used in the analysis of dental implants.\textsuperscript{3} Electrical strain gauges are used to determine deformation in relation to the forces exerted on implants and their transfer to the supporting structures.\textsuperscript{2}

Therefore, the goal of this study was to evaluate the biomechanical effects of a platform-switching implant connection on the surrounding bone using two different abutment materials and implant-supported monolithic zirconia restorations. The hypothesis of this study was that implant-abutment platform-switching design and abutment materials may affect the stress distribution around implant-supported restorations.

**Materials and Methods**

An anatomically correct model (Banna Model), which accurately replicates the anatomical features of the teeth, was used as a master model. To create an edentulous span, the mandibular first molar was removed to be replaced by a dental implant. Two tapered implants with an 11.5-mm length and a 3.7-mm upper platform diameter were used in this study (Implant Direct), representing two models. The first implant was connected to two ready-made straight titanium abutments 6 mm in length with a 3.7-mm diameter (regular platform) and a 3.0-mm diameter (platform-switch), and the other implant was connected to two zirconia abutments 6 mm length with a 3.7-mm diameter (regular platform) and a 3.0-mm diameter (platform switch) (ScrewPlant, Implant Direct).

Each implant was inserted in the socket of the first molar of the mandibular model. The implant was positioned in its corresponding socket using a parallelogrameter (BEGO) and fixed in place using KRL blue inlay wax (Kerr).

For duplication of the cast model, a custom-made tray (chemically activated acrylic resin, Acrostone) was fabricated over the mandibular model. The tray was coated with adhesive material (Polyether Adhesive, 3M ESPE) and left to dry. Medium viscosity polyether impression material (Impregum Soft Polyether Impression Material, 3M ESPE) was used to make a negative representation of the mandibular master model with the implant in its position. The impression material was dispensed into the tray using an auto-mixing machine (Pentamix 2, 3M ESPE). The implant was removed from the master model, cleaned of any wax remnants, and then repositioned in its corresponding place in the impression.

The impression was poured incrementally under vibration with chemically activated acrylic resin material (Kemapoxy 150, CMB). Two master models were obtained and placed in a pressure vessel (Vertex MultiCure, Vertex Dental) under 2.5-bar pressure at room temperature for elimination of any air bubbles, then left to set for 24 hours for complete polymerization of the material. Two epoxy resin models were constructed: one model represented a platform-switching connection with titanium and zirconia abutments, and the second model represented a standard platform design with titanium and zirconia abutments.

Samples were distributed in groups according to their implant-abutment connection, with standard platforms in Group A and platform-switching in Group B. Each group was divided into two subgroups: subgroup 1: included the titanium abutment and subgroup 2 included...
the zirconia abutment. Each subgroup received 5 monolithic zirconia crowns, for a total number of 20 crowns.

The titanium and zirconia abutments with standard or switching platforms were tried over their respective epoxy model cast for seating (Fig 1). The model was covered with an optical reflection medium (CEREC Optispray, Dentsply Sirona) for optical impression. Scanning of each model was performed using a CEREC Omnicam scanner (Dentsply Sirona). Four scans were performed for every subgroup. inLab MC X5 (Dentsply Sirona) universal five-axis production unit (software 15.1) was used to design and mill full anatomical monolithic zirconia (inCoris TZI, Dentsply Sirona) crowns. A flat area was created in the middle of the occlusal surface for reproducibility and accommodation of placing the tip of the loading machine’s loading pin in the same location each time (Fig 2). Parameters were adjusted to have an 80-μm spacer for all constructed crowns. Minimum values of 1,000 μm and 1,500 μm were set for radical and occlusal thicknesses, respectively.

Sintering of zirconia crowns was done in an inFire HTC speed high-temperature furnace (Dentsply Sirona) following manufacturer’s instructions. Each crown was tried over its corresponding titanium and zirconia abutment for accurate adaptation (Fig 3). Preparation of the models was done, and a flat, 1-mm-thick area of epoxy was left around the implant at 4 different sites (buccal, lingual, distal, and mesial) to be ready for strain-gauge bonding. Four strain gauges (7 mm long, 1 mm thick, 5.2 mm wide; CC-33A, Kyowa) were installed on their corresponding prepared sites (buccal, lingual, distal, and mesial) of the implant-supported crown on each epoxy model in order to monitor the effect of the applied static axial loads. They were bonded using a cyanoacrylate-based strain-gauge adhesive (Daiso) in a vertical position parallel to the long axis of the implant (Fig 4). Strain gauges were left for 24 hours (curing period of the adhesive).

The internal surfaces of the crowns were treated with 50-μm Al₂O₃ particles using an airborne-particle abrasion device (Renfert). The alumina particles were applied to the bonding surfaces at 2-bar pressure for 20 seconds following the manufacturer’s instructions, then ultrasonically cleaned with compressed air for 5 minutes to eliminate blasting particles. RelyX Temp NE (3M ESPE) was used for fixation of the crowns onto the implant abutments.

A specially designed cementing device was used to apply a static load of 3 kg during cementation of the crowns on their respective abutments and left for 5 minutes to standardize the pressure on all crown samples. The strain gauge...
sensors were connected to the different channels of the strain meter (CC-33A, Kyowa) to measure the microstrains that result from the applied load. The meter was connected to a compatible computer containing the meter control software (PCD-300A, Kyowa). The model was attached to the base of a fully digitalized universal testing machine (LRX Plus, LLOYD Instruments) in a horizontal plane. Vertical static load was applied from 0 to 300 N. The load was applied through a special rod applicator with a round 6-mm end perpendicular to the center of the flat occlusal fossa surface of the crowns; the machine was running at a crosshead speed of 0.5 mm/minute. A tin foil is applied below the load applicator at the center of the crown to ensure even stress distribution. Load was applied, and microstrains were recorded with strain gauges from the multichannel strain meter. The outcome intended from this study is the stress distribution using a strain gauge analysis. Collected data were analyzed using SPSS statistical software (Nexygen-MT-4.6, software 4.3, Lloyd Instruments). Data from the four groups were collected, tabulated, and statistically analyzed. The facts were summarized as means and standard deviations.

**Results**

One-way analysis of variance followed by pair-wise Tukey post-hoc tests were performed to detect significance between groups ($P = .05$). Student $t$ test was performed to detect any statistical significance between paired groups. The level of significance was set at 5% for all statistical analyses and the confidence interval at 95% (95% CI).

It was found that the zirconia standard connection group recorded the highest mean strain value (440.83 $\mu$ε). It was followed by the titanium standard connection group, which recorded a mean strain value of 431.25 $\mu$ε. The zirconia platform-switching group recorded a mean strain value of 235 $\mu$ε, and the titanium platform-switching group recorded the lowest strain mean value (216.25 $\mu$ε). All these data were lower than the clinically acceptable microstrain level (3,000 $\mu$ε) that is indexed as the threshold for cortical bone-fatigue failure.

No statistical difference was observed when comparing different materials ($P = .05$). However, when comparing designs, a statistical difference was found. Standard implant-abutment–connection groups recorded statistically significant ($P < .05$) higher mean strain values compared to platform-switching connection groups, which recorded the lowest mean strain values. The titanium standard group recorded a statistically nonsignificant ($P > .05$) lower mean strain value (431.25 $\mu$ε) than the zirconia standard group (440.83 $\mu$ε), as indicated by Student $t$ test. It was found that the titanium platform-switching group recorded a statistically nonsignificant ($P > .05$)
lower mean strain value (216.25 με) than the zirconia platform-switching group (235 με) (Student t test). The mean values and standard deviations of strain were recorded and are summarized in Table 1 and shown graphically in Fig 5.

Discussion

The results of this study do not fully support accepting the research hypothesis, as it was concluded that the mismatched implant-abutment platform affects peri-implant bone, but abutment materials have no effect.

In this study, two types of implant-abutment platforms (regular and platform-switched), two types of ready-made abutments (titanium and zirconia), and one type of superstructure crown material (inCoris TZI) were examined. To ensure standardization, one computer-aided design/computer-assisted manufacture system was used in this study for the construction of zirconia crowns. Anatomically simulated mandibular models were constructed from saturated epoxy resin. The epoxy resin was used as a cortical bone simulant (E = 13.7 GPa) with an elastic modulus close to human cortical bone (E = 15 GPa).16

All implants used in this study were 11.5 mm long. Two different implant-abutment platform connections were used: standard (3.7-mm implant body diameter and 3.7-mm abutment diameter) and platform-switched (3.7-mm implant body diameter and 3-mm abutment diameter). In this study, rather than drilling the implant into the simulated mandibular block, pouring epoxy resin around the implants was performed to ensure complete integration between both the epoxy resin and the threads of the implant and to avoid occurrence of microcracks that affect the spread of stresses during mechanical loading.17 A surveyor (BEGO) was used to guarantee standardization of implant position in the socket of anatomical models before taking an impression.

Monolithic inCoris TZI crowns were cemented on their respective titanium and zirconia abutments using RelyX temporary cement to simulate the clinical condition.18 Bonded strain gauges evaluated the strain that developed around

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<th>Table 1 Comparison Between Strain Values in the Four Groups</th>
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SD = standard deviation; SE = standard error; CI = confidence interval. Statistical significance was set at P < .05. Lowercase letters in a column indicate a statistically significant difference.
the implants during static loading. The strain gauges (7 mm long, 5.2 mm wide, and 1 mm thick) were adhered to the four prepared flat surfaces in the epoxy resin around the implants; these surfaces were flat in order to avoid strain increase caused by attaching the gauge on a bent surface.

A flat surface was designed in the center of the crown during crown construction to provide a stable area for the 6-mm tip of the axial loading machine to be seated without slippage. The 300-N load applied did not accurately reproduce the complex forces that are exerted during chewing, and that is why the obtained strains cannot be directly compared with the threshold strain.

The control group (standard connection) showed the highest significant mean strain values compared to platform-switching groups. The results concur with the hypotheses and results of other studies that suggested crestal bone height loss was altered when the platform-switching concept was used. Canullo et al observed an inverse relationship between the extent of implant-prosthetic platform-switched component and the amount of bone loss; the greater the difference, the lower the bone loss at the peri-implant crest. However, Maeda et al concluded that the platform-switching system generates an increase in stress inside the prosthetic component and retaining screw, which may lead to maladjustment, fracture, or loosening of the screw. Kielbassa et al stated that an implant-abutment connection did not present a significant difference, and Gardner and Singla et al stated that the platform-switching technique has potential disadvantages, such as the need for enough space to develop a proper emergence profile.

From the authors’ research study point of view, the biomechanical rationale for the success of the platform-switching concept is that marginal bone remodeling is relocated more distant from the stress-concentration zone and is directed to the axis of the implant. The results of the present study suggest that the stress distribution in bone is independent of abutment material and there was a statistically insignificant difference. These results were in agreement with Gao et al and El-Anwar et al, who mentioned that more-rigid abutment materials may be preferable but have a negligible effect on bones.

One major limitation of this study was the inability to construct a greater number of cast models resembling the number of samples due to variations that would be evident in the cast models. The study shows that stress distribution is more favorable with platform-switching, but this might not be the case if different prosthesis designs were used. Further limitations include the implant location, type of implant, and the prosthetic design, which can bring other surgical limitations to the process. Therefore, platform-switching is not the only factor responsible for preserving crestal bone postoperatively but may be one of them. The present study can be considered part of a series of ongoing studies focusing on platform-switching design and the potential differences among different implant platforms and abutment designs, hoping to increase understanding in this field.

Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. The platform-switching concept showed a better crestal bone stress distribution around implant-supported restorations.
2. Abutment materials expressed no statistically significant effect on the stress distribution around implant-supported restorations.
3. Zirconia and titanium abutments could withstand the functional loads developed during physiologic chewing in the molar area.

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References


