# Microstrains Around Standard and Mini Implants Supporting Different Bridge Designs

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The purpose of the study was to analyze microstrains around small- versus standard-diameter implants used in restoration of thin wiry ridge through different bridge designs. Additionally, influence of the site of occlusal vertical loading was evaluated using strain gauges. Two models simulating mandibular unilateral free-end saddle were fabricated. Two standard-size implants (3.75 × 13 mm) were inserted in one model in the position of the second premolar and first molar to support 2 3-unit cantilever bridges (NiCr alloy). On the other model, a standard implant and a mini implant (3.0 × 13 mm) were inserted in the position of the second premolar and second molar, respectively, to support 2 fixed-fixed 3-unit NiCr bridges. Four strain gauges were mounted buccally, lingually, mesially, and distally adjacent to each implant. The prostheses were temporarily cemented. A 300 N vertical load was applied on the middle of the horizontal runner bar connecting the prosthetic units and on the center of the pontics. Microstrains were recorded and analyzed. Cantilever bridges recorded higher microstrains than fixed-fixed bridges for both loading conditions. Yet, for both designs, loading on the horizontal runner bars, which apply an equal load on all bridge units simultaneously, resulted in significantly lower microstrain values than applying the load only on the pontics. Mini implant revealed greater strain values than standard implant supporting the same fixed partial denture. The best treatment option that produced the least microstrains was the fixed-fixed bridge with a mini implant as a terminal abutment. Mini implants induced higher microstrains than standard implants.

***Key Words: oral implantology, prosthodontics, implants, strain development***

## INTRODUCTION

Implant dentistry represents a reliable solution to situations that cannot be treated with conventional techniques, such as free-end saddles and long-span edentulous ridges. Today, the continued high rate of success achieved with osseointegrated dental implants allows a greater number of patients to enjoy the benefits of fixed rather than removable restorations.[1,2] Osseointegration and prognosis are greatly influenced by the biomechanical environment. The internal stresses that develop in an implant system and surrounding biological tissue under an imposed load have a significant influence on the long-term longevity of the implant.[3,4] These stresses may induce

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strains on both the implant and the surrounding bone with the probability of bone resorption and loss of the implant.[5–7] These induced strains are the engineering strains that signify the ratio of changed dimension divided by the original dimension, while microstrains are reported in parts per million.

The major factors affecting transmission of stresses from the prostheses to the implant–bone interfaces include the material and design of the supporting prostheses and the implant geometry,[5] It has been suggested that implants be positioned as perpendicular to the occlusal plane as possible,[8] and the corresponding prostheses should be designed with a geometry that will minimize the peak bone stress caused by standard loading,[9] In the presence of a thin faciolingual alveolar ridge, different prosthetic options have been suggested as an alternative to bone grafting for treatment of these cases. A mini implant ($\leq$3 mm diameter) has the potential to assist in this challenge because it can be used as a terminal support for a conventional fixed partial denture (FPD), while a standard-sized implant is used as a mesial support.

Another prosthetic option is to support a cantilever bridge on 2 mesially placed standard-sized implants. Cantilever designs were previously recommended for implant-supported prostheses, yet the forces these cantilever designs place on the implant fixtures and the supporting bone are questionable, especially in posterior regions.[10,11] The diameter of root-form implants ranges from approximately 1.8 mm to 6 mm. Three general categories of implant diameter are available: the mini implant ($\approx$1.8 mm), the standard-sized implant ($\approx$3.75 mm), and the wide-body implant ($\approx$6.0 mm) with all sizes in between.[12] The role of implant diameter in stress transfer along the bone-implant interface was investigated by Misch and Bidez,[13] who stated that an increase in implant width adequately increases the area over which forces are dissipated. In the range of 3.3 to 5.3 mm diameter implants, for every 0.5 mm increase in width, there is an increased surface area between 10% and 15%, and this percentage change is greater for smaller diameters and lesser for larger diameters. Also, the result of a finite element analysis carried out by Matsushita et al[14] showed that stresses in cortical bone decreases in inverse proportion to an increase in implant diameter with both vertical and lateral loads. Similar results were observed by Himmlova et al[15] and Tuncelli et al,[16] who showed that an increase in the implant diameter decreased the maximum stress around the implant neck. The mini-diameter implants have been used successfully as interim implants to support provisional prostheses while larger-diameter implants were integrated to bone. Research publications and clinical technique articles have described their use.[17–19] but the use of small-diameter implants as a full support and retention for fixed partial denture is still under investigations. Therefore, the purpose of this study is to investigate the effect of 2 different bridge designs on microstrains induced in bone surrounding implants with different diameters under simulated occlusal vertical loading using strain gauges.

## MATERIALS AND METHODS

The primary focus of this study was the change in the magnitude of strain as the implant type (standard-diameter implant versus mini implant) and the bridge design (fixed-fixed bridge versus cantilever bridge) were varied.

A standard-diameter implant (3.75 mm diameter × 13 mm length) and a mini implant (3.0 mm diameter ×13 mm length) were investigated under a standardized test setup. Implant assemblies were embedded in epoxy resin models. These implants were used to support different bridge designs.

### Fabrication of the epoxy resin models

Two mandibular models were fabricated to allow testing of the effect of different bridge designs on the microstrains in the bone surrounding implants of different diameters. An anatomically correct mandibular model was used to construct the models to which the implants would be embedded. To create a mandibular class II Kennedy partially edentulous span, which is a unilateral free-end saddle, the mandibular second premolar and all the mandibular molars were removed, and their sockets were sealed with wax. Putty addition silicon impression material (President fast, Coltene/Whaledent, Altstatten, Switzerland) was used to make an impression for each mandibular master model. Teeth were repositioned in their places in the impressions. Auto polymerizing epoxy resin (Epoxy-Die, Ivoclar-Vivadent Srl, Schaan, Liechtenstein) was mixed and used to fill the 2 impressions of the master model; then, after setting, the duplicated models were removed from the impressions and finished.

### Implants insertion

Two internally hexed standard-size implants (3.75 × 13 mm, 3.5 platform) (Screw Plant, Legacy system, Implant Direct LLC, Calabasas Hills, Calif), were inserted in one model in the position of the second premolar and the first molar to support a cantilever bridge. On the other model, a standard-size implant (3.75 × 13 mm, 3.5 platform) and a mini implant (3.0 × 13 mm) (Screw Direct one piece, Spectra system, Implant Direct) were inserted in the position of the second premolar and the second molar, respectively, to support a fixed-fixed bridge. Sites for implant placement were sequentially prepared with the corresponding drills supplied by the manufacturers and the aid of the surveyor to ensure parallelism between implants in each model. Implants were inserted in the corresponding sites and luted with cyanoacrylate adhesive. Then, straight contoured implant abutments (3.5-mm platform diameter) (Legacy system, Implant Direct) for cement-retained restorations were attached to the standard-size implants with abutment fixation screws tightened to 30 Ncm using a torque wrench. The mini implant was supplied with the abutment attached to it as one piece.

### Fixed partial denture fabrication

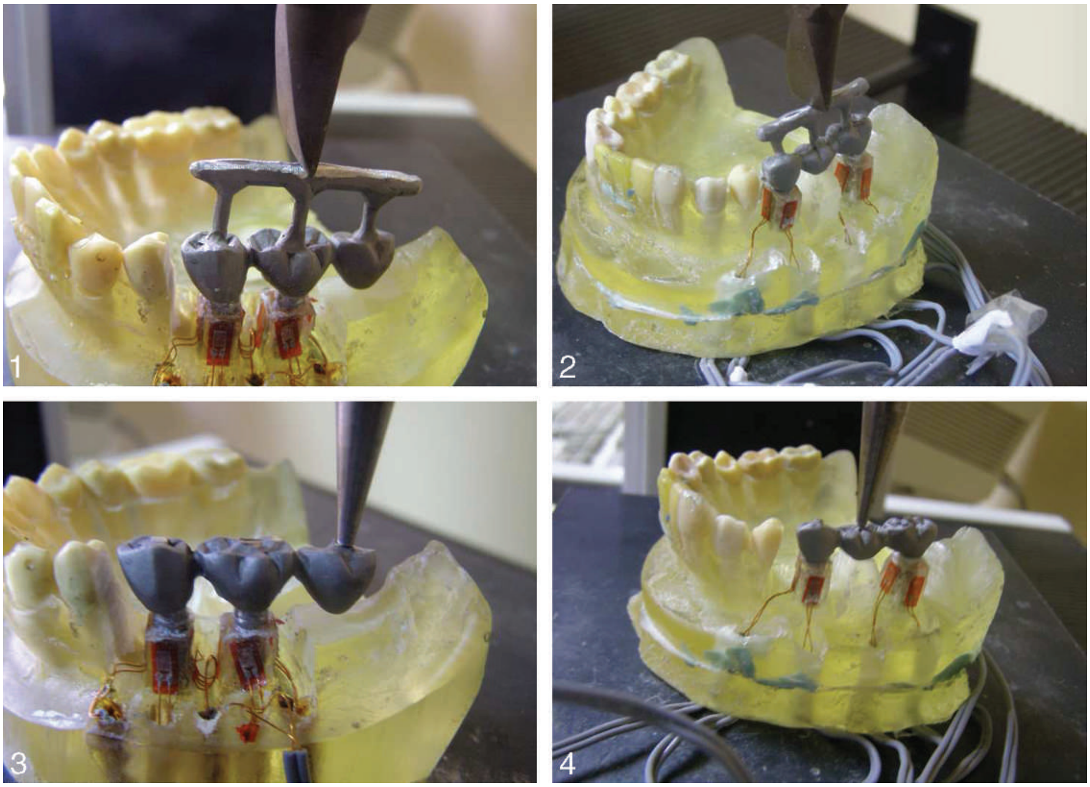
Four FPDs were constructed from a base metal alloy (NiCr alloy, Wiron 99, BEGO, Bremer, Germany) with shallow cusp slops on the occlusal surface, representing 2 different options for restoring a long-span free-end saddle.

The first FPD was a 3-unit cantilever bridge supported mesially on 2 standard-size implants inserted in the site of the second premolar and the first molar, with a suspended pontic replacing second molar. The bridge was supplied with a horizontal runner bar attached to small sprues that emerged vertically from the central fossea of the retainers and the pontic of the bridge, parallel to the long axis of the implants. These runner bars were used to apply an evenly distributed load on the different bridge units at the same time.

The second FPD was a 3-unit fixed-fixed bridge supported from one end on a standard-size implant placed in the second premolar site and supported from the other end on a mini implant placed in the site of the second molar and a pontic replacing the first molar. The bridge was supplied with a runner bar connecting different parts of the bridge.

The third FPD was a 3-unit cantilever bridge supported mesially on 2 standard-size implants inserted in the site of the second premolar and the first molar with a suspended pontic replacing the second molar. The bridge was constructed without the horizontal runner bar and was used to apply load at the pontic of the bridge.

The fourth FPD was a 3-unit fixed-fixed bridge supported from one end on a standard-size implant placed in the second premolar site and supported from the



**Figures 1–4. Figure 1.** Cantilever bridge loaded in the middle of the runner bar. **Figure 2.** Fixed-fixed bridge vertically loaded on the middle of the runner. **Figure 3.** Cantilever bridge vertically loaded on the pontic. **Figure 4.** Fixed-fixed bridge vertically loaded on the pontic.

other end on a mini implant placed in the site of the second molar and a pontic replacing the first molar. The bridge was constructed without the runner bar.

### *Measurements*

Each measurement model was equipped with 8 strain gauges (Tokyo Sokki Kenkyujo Co, Ltd, Tokyo, Japan), so that each implant received 4 strain gauges, which were placed on the mesial, distal, buccal, and lingual surfaces of the epoxy resin adjacent to the implants. At these selected sites, the thickness of the epoxy resin of the test model was reduced to approximately 1 mm and was adjusted to be parallel to the long axis of the implant/abutment. Active strain gauges were bonded to their corresponding sites using cyanoacrylate adhesive. The lead wire from each active strain gauge was connected to a multichannel strain meter to record the microstrains transmitted to each strain gauge. After temporary cementation of each FPD on its corresponding implants, all strain gauges were set to zero.

Functional loads of 300 N were applied to the 2 prostheses using a universal testing machine (model LRX-plus, Lloyd Instrument Ltd, Fareham, UK). The machine is computer controlled by the Nexygen version 4.3 software (Nexygen-MT-4.6, Lloyd Instruments Ltd, Fareham, UK), which permits the collection of the data. Two types of static axial loads were applied with 0.5 mm/min speed; the first load was 300 N, applied axially in the middle of the runner bar of the first and second FPDs (Figures 1 and 2, respectively); the second load was 300 N, applied axially on the pontics of the other two FPDs (Figures 3 and 4, respectively).

The F/L and M/D strains were recorded separately for each strain gauge. All

TABLE 1

Means ± SD of microstrains of different bridge designs subjected to vertical loading centrally on the runner bar†

| | Buccal | Lingual | Distal | Mesial | *P* Value |
|---|---|---|---|---|---|
| Cantilever bridge (first molar) | +650.5 ± 34.7<br>AE | −210.5 ± 11.7<br>DH | −177.0 ± 10.2<br>CH | +406.9 ± 23.5<br>BE | <.001* |
| Cantilever bridge (second premolar) | +602.9 ± 25.6<br>AF | −123.9 ± 10.3<br>CG | −86.3 ± 9.4<br>BF | −607.6 ± 31.5<br>DH | <.001* |
| Fixed-fixed bridge (second molar/ mini implant) | −727.2 ± 43<br>DH | +583.7 ± 21.4<br>AE | +411.5 ± 8.9<br>BE | −313.5 ± 11.4<br>CG | <.001* |
| Fixed-fixed bridge (second premolar) | −349.3 ± 20.4<br>DG | +234.4 ± 17.8<br>BF | −134.0 ± 11.3<br>CG | +248.8 ± 18.3<br>AF | <.001* |
| *P value* | <.001* | <.001* | <.001* | <.001* | |

*Significant at $P \leq .05$.

†A, B, C, and D indicate differences between surfaces; E, F, G, and H indicate differences between bridge designs.

recordings were repeated 3 times, allowing the strain indicator to recover to zero strain before reloading. The 3 recordings were averaged, and the range of recordings was noted to assess the reliability of the recording system.

Electric strain gauges used were 2 mm in length, 2.1 ± 1% gauge factor, and 119.8 ± 0.5 Ω resistance; the gauges use property of the resistive element, which changes its electric resistance when strained. The gauges were used to measure the strain induced around implants after load application by measuring the change in resistance and then calculating the amount of strain at the site of their attachment using the following equation: gauge factor (GF) = ΔR/R over ΔL/L or GF = ΔR/R over E, where R = gauge resistance, ΔR = change in resistance during elongation, L = initial gauge length, ΔL = change in length, and E = strain being measured.[20,21]

### *Statistical analysis*

Data were presented as arithmatic means and SDs values. Data were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. The results indicated that data were normally distributed (parametric data). Testing for homogeneity of variances is given by the Levene test which indicated homogeneity of variances among the groups. Repeated measures analysis of variance was used to compare between mean microstrain values among different surfaces and different bridge designs. The significance level was set at $P \leq .05$. Statistical analysis was performed with SPSS 16.0 (Statistical Package for Scientific Studies, SPSS Inc, Chicago, Ill) for Windows.

## RESULTS

Following is an interpretation of the study results:

1. Cantilever bridge with central loading on the runner bar: The highest tensile microstrains were recorded in the area adjacent to the buccal surface of the 2 implants (+650.5 ± 34.7 and +602.9 ± 25.6) (*P* value < .001), and the highest compressive microstrains were recorded in the area adjacent to the mesial surface of the implant replacing the second premolar (–607.6 ± 31.5) (*P* value < .001) (Table 1).
2. Fixed-fixed bridge with central loading on the runner bar: The highest tensile microstrains were recorded in the area adjacent to the lingual surface of the mini implant replacing the second molar (+583.7 ± 21.4) (*P* value < .001), and the highest compressive microstrains were recorded in the area adjacent to the

Table 2

Means ± SD of microstrains of different bridge designs subjected to vertical loading on the pontic†

|  | Buccal | Lingual | Distal | Mesial | *P* Value |
|---|---|---|---|---|---|
| Cantilever bridge (first molar) | +827.7 ± 34.6<br>BE | −334.5 ± 18.3<br>CG | −1904.6 ± 11.4<br>DH | +1328.8 ± 25.8<br>AF | <.001* |
| Cantilever bridge (second premolar) | +803.8 ± 23.7<br>BF | −81.3 ± 22<br>CF | −1762.3 ± 25.6<br>DG | +1682.2 ± 32.8<br>AE | <.001* |
| Fixed-fixed bridge (second molar/ mini implant) | −1593.2 ± 42.8<br>DH | +760.7 ± 30.2<br>BE | +851.6 ± 27.4<br>AE | −540.7 ± 20.1<br>CH | <.001* |
| Fixed-fixed bridge (second premolar) | −119.6 ± 21.4<br>CG | −85.7 ± 10.1<br>BF | −433.2 ± 22.5<br>DF | +368.4 ± 24.1<br>AG | <.001* |
| *P value* | <.001* | <.001* | <.001* | <.001* |  |

*Significant at $P \leq .05$.

†A, B, C, and D indicate differences between surfaces; E, F, G, and H indicate differences between bridge designs.

buccal surface of the same implant (−727.2 ± 43) (*P* value < .001) (Table 1).

3. Cantilever bridge with axial loading on the pontic: The highest tensile microstrains were recorded in the area adjacent to the mesial surface of the implant replacing the second premolar (+1682.2 ± 32.8) (*P* value < .001), and the maximum compressive microstrains were recorded in the area adjacent to the distal surface of implant replacing the first molar (−1904.6 ± 11.4) (*P* value < .001) (Table 2). High compressive microstrains were recorded in areas adjacent to the distal surface of both implants, and high tensile microstrains were recorded in areas adjacent to the mesial surfaces of both implants, indicating a tendency for torque forces on the implants.
4. Fixed-fixed bridge with axial loading on the pontic: The highest tensile microstrains were recorded in the area adjacent to the distal surface of the mini implant replacing the second molar (+851.7 ± 27.4) (*P* value < .001), and the highest compressive microstrains were recorded in the area adjacent to the buccal surface of the mini implant (−1593.2 ± 42.8) (*P* value < .001). Thus, the highest microstrains were recorded in relation to the mini implant (Table 2). High compressive microstrains were recorded in areas adjacent to the distal surface of the anterior implant and adjacent to the mesial surface of the posterior implant, and high tensile microstrains were recorded in the area adjacent to the mesial surface of the anterior implant and adjacent to the distal surface of the posterior implant, which indicates the tendency of the bridge to flex under loading.

On comparing the 2 designs, the cantilever bridge design recorded higher microstrain values than the fixed-fixed bridge design when loaded on the runner bar and when loaded on the pontic, yet generally, for both designs axial loading on the runner bar resulted in significantly lower microstrain values than axial loading on the pontic. Also, higher microstrains were recorded in conjunction with the mini implant compared with those recorded with the standard-size implant supporting the same FPD.

## Discussion

The rationale for the investigated parameters regarding prosthetic design and implant type is based on the idea of predicting the best treatment option to achieve long-term clinical success in patients with thin wiry ridges without subjecting them to surgical alveolar grafting. This article described an experimental study aimed at determining the mandibular strains provoked by vertical loads on implants with different diameters supporting 2 different bridge designs.

As the type of strains are dependent on the point of load transfer and the design of the prosthesis, the study evaluated induced strains through a simulation of 2 cement retained prosthetic options with different points of load application.

The strains on dental implants were tested under 300 N static axial loading conditions, which were considered to be the average functional loads in the posterior region.[22,23] In the case of the bridges that had a runner bar connecting its units, the load was applied in the middle of the bar so as to transfer the load simultaneously and evenly to the bridge units. In the case of the bridges lacking the runner bar, the load was applied on the pontic to study the effect of pontic loading in different designs.

It has been reported that the physiologic loading zone is in the 1000 to 3000 microstrain range,[24] whereas ranges over 4000 may cause micro-fractures at the bone-implant interface,[25,26] thus leading to implant failure. So these levels were taken as a guide to estimate the effect of loading in different conditions.

Results revealed that strains were concentrated at the points of load application, and they were significantly greater in the FPDs without the runner bar than in those with the runner bar (Tables 1 and 2). This was attributed to the fact that the runner bar led to even distribution of the falling load on all the bridge units and along their long axis. Also, the application of axial load on the pontic resulted in off-axial loading of the corresponding implants, thereby creating a moment arm and yielding a significant increase of microstains in the surrounding area,[27] compared with those recorded with the runner bar.

In the fixed-fixed bridge design, when axial load was applied on the pontic, results revealed load partitioning between the supporting implants, yet significantly higher strains were detected in conjunction with the mini implant that was used as a distal support (Table 2). That was in agreement with Cehreli and Akca[28] and Matsushita et al,[14] who stated that the use of narrow diameter implants resulted in an overall increase in stress and strain magnitudes around supporting implants. That might be due to the smaller surface area and volume of these implants, which places more force per square millimeter against the encasing bone than do larger diameter implants, as explained by Flanagan.[9] It was concluded that implant diameter has a significant influence on the stress distribution in bone because of different load transfer mechanisms and because of its diminished ability to withstand off-axial loading.

In cantilever bridge design, when axial loading was applied on the cantilevered pontic, it resulted in a dramatic increase in load transferred distal to the most distal implant (Table 2). These results were consistent with the findings of several authors who stated that cantilever design tends to create a lever arm, which causes bending moments in the implant abutments and the surrounding bone.[10,29,30] The magnitude of strains found around the most distal implant approached the level of overloading, which might indicate the potential for microfracture to occur over time under the tested loading conditions. The findings of this study were consistent with the results of studies that have revealed that excessive stresses are concentrated in the cortical bone adjacent to the terminal support of the cantilever extension, which may represent a clinical hazard.[31,32]

On comparing the 2 designs, the highest compressive microstrain recorded in conjunction with the cantilever design was $-1904.56 \pm 11.4$ at the distal surface of the posterior implant, which was close to the physiologic loading zone or the physiologic tolerance threshold of bone. Although the highest compressive microstrain recorded with the fixed-fixed bridge design was −1593.2 ± 42.8 at the buccal surface of the mini implant, which was significantly lower than that of the cantilever design (Table 2).

The highest recorded tensile value in conjunction with the cantilever design was +1682.2 ± 32.8 at the mesial surface of the anterior implant, and the highest tensile microstrains recorded with the fixed-fixed bridge design was +851.6 ± 27.4 at the distal surface of the mini implant, which was significantly lower than that of cantilever design (Table 2).

These results revealed that the cantilever FPD caused significantly higher strains compared with the strains created by fixed-fixed partial denture design. This was in agreement with Yokoyama et al[33] who found that the maximum equivalent stresses in an FPD with a central pontic was less than half of that seen in the cantilever FPD.

One of the limitations of this study was that osseointegration was not achieved; therefore, direct transfer of the magnitude of data values recorded to an actual clinical patient situation may not be appropriate. Yet the trends in mean strain values and the locations and directions of the strain under the various conditions tested are applicable to patients.

## CONCLUSIONS

1. The recorded compressive and tensile microstrains for the tested designs were within the physiologic loading range as they did not exceed the compressive or tensile strength of the bone–implant interface, which is more than 3000 microstrains.
2. The point of load transfer affected microstrains on implants. For all prosthetic designs, axial loading on the pontics generated more microstrain than axial loading on the runner bar.
3. Although both designs were within the physiologic tolerance of bone, the cantilever bridge caused microstrains close to the high physiologic tolerance of bone, which might cause clinical failure over time.
4. Use of mini implants is a clinically acceptable option, yet off-axial loading should be minimized as it produced significantly higher microstrains than the standard-sized implant.

## CLINICAL SIGNIFICANCE

Within the limitations of this study, the best treatment option, that is, the one that produced the least microstrains in the simulated bone model, was the fixed-fixed bridge with the mini implant as the terminal abutment. Yet efforts should be made to decrease off-axis loading on its supporting abutments as the mini implant produced higher microstrains than standard-sized implants.

## ABBREVIATION

FPD: fixed partial denture

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