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# Straight and Offset Implant Placement under Axial and Nonaxial Loads in Implant-Supported Prostheses: Strain Gauge Analysis

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## Abstract

**Purpose:** The aim of this in vitro study was to quantify strain development during axial and nonaxial loading using strain gauge analysis for three-element implant-supported FPDs, varying the arrangement of implants: straight line (L) and offset (O).
**Materials and Methods:** Three Morse taper implants arranged in a straight line and three implants arranged in an offset configuration were inserted into two polyurethane blocks. Microunit abutments were screwed onto the implants, applying a 20 Ncm torque. Plastic copings were screwed onto the abutments, which received standard wax patterns cast in Co-Cr alloy (n = 10). Four strain gauges were bonded onto the surface of each block tangential to the implants. The occlusal screws of the superstructure were tightened onto microunit abutments using 10 Ncm and then axial and nonaxial loading of 30 Kg was applied for 10 seconds on the center of each implant and at 1 and 2 mm from the implants, totaling nine load application points. The microdeformations determined at the nine points were recorded by four strain gauges, and the same procedure was performed for all of the frameworks. Three loadings were made per load application point. The magnitude of microstrain on each strain gauge was recorded in units of microstrain ($\mu\varepsilon$). The data were analyzed statistically by two-way ANOVA and Tukey's test ($p < 0.05$).
**Results:** The configuration factor was statistically significant ($p = 0.0004$), but the load factor ($p = 0.2420$) and the interaction between the two factors were not significant ($p = 0.5494$). Tukey's test revealed differences between axial offset ($\mu\varepsilon$) (183.2 ± 93.64) and axial straight line (285.3 ± 61.04) and differences between nonaxial 1 mm offset (201.0 ± 50.24) and nonaxial 1 mm straight line (315.8 ± 59.28).
**Conclusion:** There was evidence that offset placement is capable of reducing the strain around an implant. In addition, the type of loading, axial force or nonaxial, did not have an influence until 2 mm.

Osseointegrated dental implants have been a well-accepted and predictable treatment modality for the rehabilitation of partially and completely edentulous patients. An implant-supported prosthesis may be under the influence of external (functional or parafunctional) and/or internal (preload) forces.[1] The magnitude of these forces affects the amount of induced strains and stresses in all components of the bone-implant-prosthesis complex.[2-8]

Strain is defined as the ratio between the length of an object under stress and its original dimension; it is a dimensionless entity. A strain gauge is considered an indirect measurement that analyzes a physical effect, mechanical deformation, based on electrical measurements taken with a device called a "transducer." In short, deformations are normally imperceptible to the naked eye, so a strain gauge is necessary to measure them. The strain gauge is an electric sensor that quantifies a superficial deformation; its working principle is based on the variation of the electrical resistance transformed into deformation levels.[9]

Mechanical stress can have both positive and negative consequences for bone tissue and, thereby, also for maintaining osseointegration of an implant.[10] It is important to design an abutment connection that distributes functional forces at a desirable level of bone strain. The bone carrying mechanical loads adapts its strength to the applied load and this continuous remodeling maintains the mechanical competence of the bone.[7,11]

The application of a functional load induces stress and strain on the bone/implant complex and affects the peri-implant bone remodeling.[12–14] A fraction of this occlusal load is transmitted to the implants, with the induced stress dependent upon where the load is applied to the prosthesis.[15,16] Excessive loading on the bone/implant interface is one of the main factors accounting for marginal bone loss, motivating this strain study.[6,17,18]

Rangert et al[19] and Sahin et al[20] indicated that the bending moment for all implants would be diminished if the implants were placed with an offset placement; however, some studies have apparent disagreements on the effect of this offset placement.[21] These studies found that the offset placement of implants did not always decrease the load in all implants.[22,23]

Mastication mainly induces vertical forces on the dentition; however, transverse forces are also created and transferred through the prosthesis into the fixture, and eventually into bone. Two main types of loading of the anchorage unit should be considered: axial load and nonaxial load. The axial force is more favorable, as it distributes stress more evenly throughout the implant, while the nonaxial load exerts stress gradients on the implant as well as in the bone.[19]

The aim of this study was to compare the influence of axial and nonaxial loading on simulated bone tissue surrounding implants, analyzed using a strain gauge. The hypothesis is that the offset implants promote decreased levels of strain than straight line does and axial load promotes less strain than nonaxial load does.

## Materials and methods

### Test specimen preparation

To simulate clinical conditions in a real-life arrangement, three straight line Morse taper implants (Conect AR; 3.75-mm diameter, 13-mm length; Connection Prosthesis Systems, Sao Paulo, Brazil) and three offset Morse taper implants (Conect AR; 3.75-mm diameter, 13-mm length) (from mesial to distal: labeled 1, 2, and 3) were arranged in the middle of two rectangular polyurethane block models[24] (F16 Axson, Cercy, France) with known mechanical properties (Young's modulus of 3.6 GPa). A set of aluminum indices, consisting of three components, was used to standardize both the straight line and offset implant placement into the polyurethane blocks and standardize the wax-up of superstructures.

Component 3 (the upper one), which standardized the distance and locations for implant placement, was fixed onto the polyurethane blocks using horizontal screws. Color-coded rings were screwed alternately into the three holes in component 3. The rings had progressively larger internal diameters, which were compatible with the standard twist drill used for implant placement (Connection Prosthesis Systems). The white ring was compatible with the 2-mm, the yellow one with the 3-mm, and the blue one with the 3.15-mm twist drills. A handpiece (contra-angle) with a reduction of 16:1 (KavoDental GmbH, Biberach, Germany) was used to make the holes and insert the implants.

Three straight line Morse taper implants (L) and three offset Morse taper implants (O), measuring 3.75 mm in diameter and 13 mm in length (Connection Prosthesis Systems), were installed into the first and second polyurethane blocks, respectively. Microunit abutments (Connection Prosthesis Systems) were screwed into the implants with 20 Ncm torque using a manual torque driver (Connection Prosthesis Systems).

### Metallic framework fabrication

The patterns were fabricated using wax (Babinete, São Paulo, Brazil), and each polyurethane block served as the base for the abutment and wax-up procedures. Plastic copings were initially positioned directly on the abutment, and the wax-up was adapted under slight pressure.

The wax patterns were sprued, invested, and one-piece cast in an induction oven[25,26] using cobalt-chromium alloy (Wirobond SG, Bego, Bremen, Germany). To avoid bias resulting from manufacturing conditions, random sets comprising superstructures of different types were put together and cast. After removal from the investment material, the sprues were eliminated using carbide discs at low speed. The castings were airborne particle abraded with 110 $\mu$m aluminium oxide (Korox, Bego), under 60 psi pressure. The castings were then ultrasonically cleaned in isopropyl alcohol (Vitasonic II, Vita, Bad Säckingen, Germany) for 10 minutes and dried at room temperature.

The frameworks were fit individually to their respective abutments and polyurethane blocks. Stability of the set was checked without torque tightening.

Each metallic structure was numbered and labeled according to its corresponding group. The whole sample was composed of 20 frameworks (n = 10) distributed randomly and equally between two groups: G1-L and G2-O.

### Strain gauge analysis

Four strain gauges (KFG-02–120-c1–11N30C2, Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan) were bonded on the surface of each polyurethane block with a thin film of methyl-2-cyanocrylate resin (Vishay Measurements Group, Raleigh, NC), which was carefully positioned and held in place under slight manual pressure for 3 minutes. Each gauge was wired separately, and the four strain gauges were connected to a multichannel bridge amplifier to form one leg of the bridge.

All strain gauges were set to zero, and then the superstructure was placed on the abutments. The screws of the occlusal frameworks were tightened in the microunit abutments using a hand-operated screwdriver, until the screws started to engage as indicated by tactile sensation. Then, they were tightened by applying a torque of 10 Ncm using the manufacturer's manual torque-controlling device. Each of the superstructures was screw tightened according the torque sequences for abutments: first screw—implant 2 (center); second—implant 1; third screw—implant 3.

An idealized load application device was connected to the electrical signal conditioning appliance (Model 5100B Scanner, System 5000, Raleigh, NC) to apply the load. The experimental model was placed on the load application appliance (Fig 1) with the framework submitted to an axial load of 30 kgf[27] applied for 10 seconds on the center of each implant and at 1 and 2 mm from the implants, totaling nine load application points (Fig 2). The reference points were designated as: A (axial

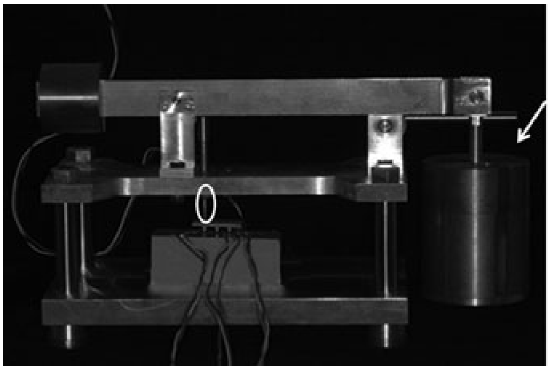

**Figure 1** Experimental model in the loading apparatus with load applied at point A. Circle: application device. Arrow: 30 kg load.

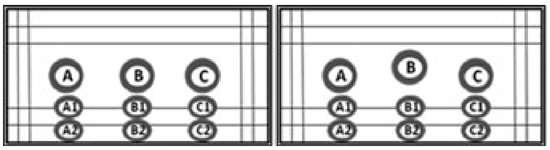


**Figure 2** Left: straight line implants. Right: offset implants.

point, center of the retention screw of implant 1), A1 (nonaxial point, 1 mm from external edge of the implant 1 prosthetic platform), A2 (nonaxial point, 2 mm from external edge of the implant 1 prosthetic platform), B (axial point, center of the retention screw of implant 2), B1 (nonaxial point, 1 mm from external edge of the implant 2 prosthetic platform), B2 (nonaxial point, 2 mm from external edge of the implant 2 prosthetic platform), C (axial point, center of the retention screw of implant 3), C1 (nonaxial point, 1 mm from external edge of the implant 3 prosthetic platform), C2 (nonaxial point, 2 mm from external edge of the implant 3 prosthetic platform). The microdeformations determined at the nine points were recorded by four strain gauges and the same procedure was performed for all of the frameworks. Three loadings were made per load application point.

The final result was an average of measurements for axial load (A, B, C), an average for nonaxial load 1 mm (A1, B1, C1), and an average for nonaxial load 2 mm (A2, B2, C2) for each framework. The electrical variations were transformed arithmetically into microstrain units ($\mu\varepsilon$) by the data acquisition software (StrainSmart, Raleigh, NC).

### Statistical analysis

The absolute strain values were compared by two-way ANOVA followed by a post hoc Tukey's test at a 95% confidence level ($\alpha = 0.05$). The absolute values of the four strain gauges were compared, as the strain gauges were only capable of detecting stresses in a limited segment around the implants and did not provide clear statements as to whether compressive or tensile forces were present in a polyurethane area of a given magnitude.

**Table 1** Two-way ANOVA for conditional experiments

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Configuration | 1 | 145,952 | 145,952 | 18.8 | 0.0004* |
| Error configuration | 18 | 139,712 | 7762 | | |
| Load | 2 | 8008 | 4004 | 1.48 | 0.2420 |
| Configuration*Load | 2 | 3304 | 1652 | 0.61 | 0.5494 |
| Error config*Load | 36 | 97,659 | 2713 | | |
| Total | 59 | 394,635 | | | |

*$p < 0.05$

**Table 2** Tukey HSD all-pairwise comparisons test of SG for configuration *point

| | Offset | Straight line |
|---|---|---|
| Axial | $183.2 \pm 93.64^{A,a}$ | $285.3 \pm 61.04^{A,b}$ |
| Nonaxial 1 mm | $201.0 \pm 50.24^{A,a}$ | $315.8 \pm 59.28^{A,b}$ |
| Nonaxial 2 mm | $219.7 \pm 66.69^{A,a}$ | $298.6 \pm 58.27^{A,a}$ |

Means followed by same capital letters in column and small letter in row do not differ significantly by Tukey's test (5%).

## Results

Two-way ANOVA revealed that the configuration factor was statistically significant, whereas the load factor and the interaction between the two factors was not significant (Table 1). Tukey's test revealed a difference between straight line axial load and offset axial load, offset nonaxial 1 mm, and straight line nonaxial 1 mm (Table 2).

## Discussion

To ensure the success of a surgical intervention for prosthodontics, the transfer of stresses and strains occurring around bone must be taken into account.[3–5,14,16,17,19] The mechanism is complex physiologically, and any mechanical model can only be an approximation of the clinical situation. This study used strain gauge analysis to compare the strain distribution during two types of load: axial and nonaxial load in three-element prostheses, varying the implant configurations (straight line and offset).

Bone quality is one factor that influences treatment with implants. The bone surrounding implants does not constitute a homogeneous substratum and its physical properties vary with the age, functional state, and systemic factors of the patient.[20] Additionally, in vitro studies have used homogeneous and isotropic materials.[22]

Associated with these factors, a homogeneous model with uniform elastic properties was used in this study to simulate human bone.[10] According to Wiskott and Belser,[10] the polyurethane block used in this study possesses a similar modulus of elasticity to human medullary bone (polyurethane: 3.6 GPa; medullary bone: 4.0–4.5 GPa); however, this represents a limitation for this study because natural anatomic structures and anisotropic properties of the mandible were not taken into consideration to allow more accurate stress prediction.

Some strain gauge studies used special devices for the application of loading on implants,[8,15] but others used universal testing machines[28] to apply the load. The quantity of load used in this work was based on the study developed by Mericske-Stern et al,[27] investigating the occlusal force in patients with fixed partial implant-supported dentures. Those authors claimed that 30.6 kgf (300 N) was the mean value for the maximum force verified in the region of the second molars,[27] justifying this same amount of load used in this study.

The biomechanical behavior of each component of the bone-implant-superstructure assembly is different. Functional loads applied on an implant may introduce complex deformation patterns in the prosthesis, the implant, and the surrounding cortical bone, which may affect the maintenance of the bone/implant interface.[12-14]

The current results demonstrated that the mean microdeformation with reference to configuration factor (Table 1) had a significant difference. This difference showed lower values for the offset configuration, compared to straight line [axial offset (183.2 ± 93.64) and axial straight line (285.3 ± 61.04); nonaxial 1 mm offset (201.0 ± 50.24) and nonaxial 1 mm straight line (315.8 ± 59.28)]. These results are in disagreement with previous studies showing that the offset placement of implants did not always decrease the load in implants.[9,22,23] Some researchers found that the offset placement could result in higher force or torque in the implants,[22] but the conditions they evaluated was limited. Sato et al[22] applied only a single force on the second molar, which restricted their observations.

Nishioka et al[7] found variable results according to the prosthetic connection used and did not show statistically significant differences for the configurations used (straight: external hexagon 140.7 ± 76.5; offset: external hexagon 245.0 ± 249.0; straight: internal hexagon 416.0 ± 337.0; offset: internal hexagon 368.7 ± 149.9); however, this study agreed with Rangert et al's results,[19] which indicated that the bending moment would be diminished if the implants were placed in an offset placement. Rangert et al[19] suggested a hypothesis that the offset arrangement of three implants would be preferred over straight line placement. The Morse taper design of the implant used in this study may also have affected the type of strain. This design involves incorporation of an abutment into the implant, and different data may be recorded with the use of external and internal hexagon designs. Offset placement of implants in the posterior region of the mouth requires sufficient width of the residual ridge, which is not often available clinically;[2] however, it is unclear whether establishing tripoded placement would counteract bending moments and/or whether it is superior to two implants supporting a prosthesis.[21]

Based on the physiological balance, clinical and laboratory studies indicate that permanent mechanical stimulation is needed.[1] Deformation intensities above 100 $\mu\varepsilon$ are necessary to prevent bone resorption; however, the stimulation values must not exceed the physiological limit of 4000 $\mu\varepsilon$.[10,18]

The data presented in Table 2 indicate that the values of microstrain are between 183.2 and 315.8 $\mu\varepsilon$, considered within the physiologic bone tolerance limit. Additionally, no differences were observed between values of microstrain when points of axial load (A, B, and C), points of nonaxial load 1 mm (A1, B1, and C1), and points of nonaxial load 2 mm (A2, B2, and C2) were compared. This result disagrees with a previous study,[19] which found that nonaxial loads cause higher microstrain than axial loads. The proximity of the implants and the short distance of the nonaxial from the axial load are probably the factors responsible for the different results found in this study.

The question arises whether the difference in axial versus nonaxial loading has a clinical significance that indicates mandatory safety measures to be followed during treatment planning. Sufficient control of offset loading of implants should be provided when possible. As the occlusal contact points in screw-retained fixed prostheses are established around the screws, offset loading of implants is inevitable.

## Conclusion

According to the limitations of this study, there was evidence that the offset placement was capable of reducing the strain around an implant. Additionally, the type of loading (axial load, nonaxial load 1 mm, or nonaxial load 2 mm) did not have an influence until the nonaxial loading was located 2 mm from the axial load.

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