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BIOMECHANICAL STUDY OF MICROSTRAINS AROUND PROSTHETIC ABUTMENTS FOR 3-UNIT FIXED PARTIAL DENTURES UNDER STATIC NON-AXIAL LOADS

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ABSTRACT

This study aimed to evaluate the microstrains around implants, generated by static non-axial loads, in miniconical and CMN abutments for 3-unit fixed partial dentures. Blocks in polyurethane were made for each evaluated group (n=10). Each block received three implants in the “off set” configuration, their respective abutment (CMN or miniconical) and 3-unit fixed partial dentures. Four strain gauges (SG) were glued on the surface of each block, tangent to each implant, to carry out the strain gauges tests. A load application device with a load of 30 kgf was used on points C, D, E and F for 10 seconds, under three repetitions, following a factorial scheme of: 2 x 3. The data obtained were statistically analyzed using the test Two-way RM ANOVA and t test on two paired samples for means ($p<0.05$). The highest microstrain mean was observed in SG 4, at application point F for miniconical (1369.68 με) and CNM abutment (1418.64 με). The results obtained by strain-gauge showed no statistical difference ($P = 0.255$) between the CMN (1102.88 με) and miniconical (1023.65 με). The study concluded that the CMN presented biomechanical behavior compatible with miniconical abutments. Therefore, the non-axial component of the CMN abutment does not seem to contraindicate its use when supporting fixed partial dentures.

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INTRODUCTION

Implantology has established itself in modern dentistry as an oral rehabilitation tool with confidence and security of results, after consolidated studies by Branemark *et al*. (1969). When studying the longevity of rehabilitation treatment, biomechanics are of great importance in preventing osseointegrated implant failure, since occlusion and overload is one of the main causes of loss of bone attachment around implants [2]. The restorative therapy with bone-integrated implants in dentistry was divided into three distinct parts, the first corresponds to the placement of the implant itself fixed to the bone through a surgical procedure, the second is the insertion of the pillar (connection, intermediary, abutment, between others) screwed, responsible for connecting the third part, which is the dental prosthesis [3]. Suppliers provide several models of abutments for the most diverse clinical cases, which are used for multiple or single prostheses, and some can be used in both situations. We have as main examples for multiple prostheses, the Mini Conical Abutments, the Mini Angled Abutments, UCLA without AR (Anti Rotational), UCLA with AR or Trunnions. As for single prostheses, we have as main examples; Universal Post, Customizable Posts, Conical Abutment (CMN), UCLA Abutment, Estheticone Abutment, Custom Abutments through CAD-CAM technology [4]. The choice of design for the prosthetic abutment has a direct relationship with the aesthetic need, in addition to being a determinant for the prosthesis to be cemented or screwed. In clinical situations with reduced interocclusal space, a viable resource is the use of prosthetic abutments called miniconical, which have a reduced coronary dimension and are suitable for multiple prostheses. The CMN abutment, on the other hand, has a geometry with a height of 3.5 mm and an anti-rotational configuration, that is, it is a component originally indicated to support single prostheses screwed onto an implant. However, the use of rotational caps on these pillars allows the construction of multiple prostheses and, if their biomechanical behavior is compatible for this purpose, their indication could be extended to different configurations of prostheses on implants. There are several tests to analyze the stress/strain resulting from the dissipation of occlusal loads on the prosthesis and/or peri-implant bone. Strain gauge (SG) is a feature that can be used that will record microstrains in the surrounding areas where the sensor is located. It is a set of techniques that allow measuring the deformation on the surface of an object through the use of reduced electrical resistors called “strain gauges”, “strain gage” or strain gauges. This technique has been used to assess microstrains in implant-supported prostheses both in vitro[7,8]. Strain gauges can be glued, depending on the assessment site, close to the implants [9,10,11,12,13,14] on the implants[15, 16] or on the metallic structures of the prosthesis[8]. As it is a proportion of length, which can be elongation or contraction, it results in an absolute value, therefore without unity, and can only be called microstrain. Therefore, the objective of this study will be to analyze the microstrains and stress concentration under static non-axial loading through the influence of CMN and miniconical abutments comparatively on the mechanical behavior of the implant-supported 3-unit fixed partial dentures, using Strain gauge analysis.

MATERIAL AND METHODS

Strain gauge analysis: For the strain gauge analysis, 20 polyurethane blocks (95 x 45 x 30 mm) (Polyurethane F16 Axson, Cercy, France) were manufactured to simulate an isotropic substrate for each group (N=20,n=10). The polyurethane resin polymerization was carried out in a vacuum pressurizer (Protecni, Araraquara, Sao Paulo, Brazil) to prevent pores. After the polymerization, the blocks were removed from the matrix and their surfaces were polished with progressive sandpaper (#220 to #600 grit) under water. A metallic die [11] was used to standardize the three implants placement (4,0 x 13 mm, Intraoss,Sistemas de Implantes, Itaquaquecetuba, SP, Brazil), perpendicular to the surface, at the bone level and in the “off set” configuration. The respective abutments were installed with the aid of a manual torque wrench and the manufacturer's guidance, 32N.cm for the CMN and 20 N.cm for the miconical abutments (Intraoss, Sistemas de Implantes, Itaquaquecetuba, SP, Brazil. The surface of the 20 blocks were cleaned with isopropyl alcohol and four unidirectional linear SGs model PA-06-060BA-120-L (Excel Sensores Ind. Com. Exp. Ltda, Taboao da Serra, Sao Paulo, Brazil, resistance 120 Ω; gauge length: 1.5 x 1.3 mm) were boned to each, positioned between the implants, with cyanocrylate adhesive (Super Bonder Loctite, Sao Paulo, Brazil) (Figure 1). Each strain gauge outlet was measured using a multimeter (Minida ET 2055: Minida SaoPaulo, Brazil), ensuring that the connector output had the same resistance (120 Ω). Four electrical cables were installed at the outputs and connected to an electrical signal conditioning apparatus (Model 5100B Scanner – System 5000 – Instruments Division Measurements Group, Inc. Raleigh, Carolina do Norte – USA, FAPESP proc: 07/53293-4) to record variations in electrical resistance and convert them in microstrain (µε/µε). The SGs data were submitted to ANOVA RM and t test with a significance level of 5% (R-project software, version 3.2.0, 2016).

RESULTS

Table 1 presents the descriptive analysis of the microstrains means values obtained in each strain gauge (SG), in the CMN prosthetic abutments, at each application point. The highest mean microstrain (1418.64µε) was observed in strain gauge 4 (SG4), at application point F. The lowest average microstrain (550.53 µε) was observed in strain gauge 1 (SG1), at application point C. Table 2 presents the descriptive analysis of the microstrains means values obtained in each strain gauge (SG), in the miniconical abutments, at each application point. The highest mean microstrain (1369.68µε) was observed in strain gauge 4 (SG4), at application point F. The lowest average microstrain (473.29 µε) was observed in strain gauge 3 (SG3), at application point. Table 3 presents the descriptive analysis of the microstrains means of values obtained at each application point, in the CMN and miniconical abutments. The results obtained showed that, although the CMN group had the highest peripheral deformation (1418.64 µε) for the type of applied load (non-axial loading), the experimental models were able to resist the required efforts without causing a peripheral deformation deleterious, ie, a deformation capable of causing peri-implant bone resorption (3,000 µε). The data obtained from the mean microdeformation values were submitted to inferential statistical analysis, by two-factor repeated measures analysis of variance. The conventional significance level of 5% was chosen. The results obtained by strain-gauge showed no statistical difference (P = 0.255) between the CMN (1102.88 µε) and miniconical (1023.65 µε). Inferential analyzes showed the effects of the primary factors (prosthetic pillar and application point) and their interaction. The means and standard deviations of the prosthetic abutments under vertical loads, analyzing the prosthetic abutment effect and the load application point effect, are represented in the figures below. (Figures 2,3,4 and 5)

Figure 1. Strain Gauges arranged between the implants and the application load points

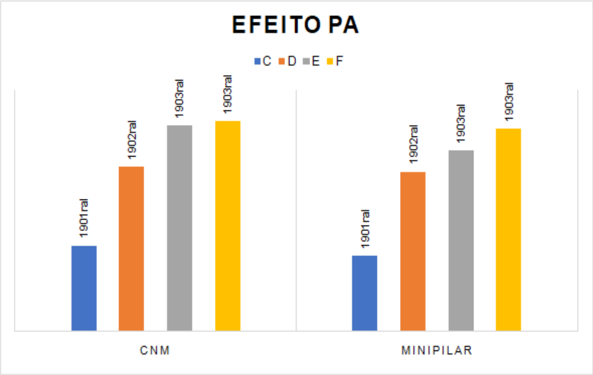

Figure 2. Microstrain mean values (µ) in relation to the load application points (PA)

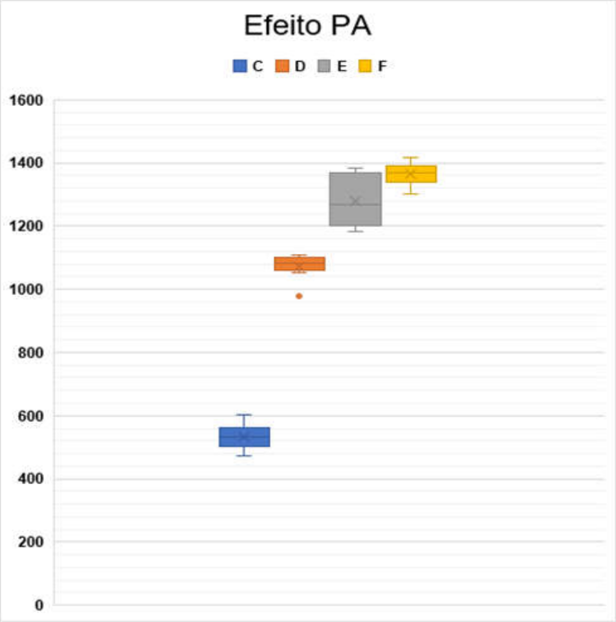

Figure 3. Box-plot plot of the of microstrain values (µ) in relation to the load application points (PA)

Table 1. Microstrains values (με) obtained at each application point on the CMN abutments

APPLICATION POINT	STRAIN GAUGE(SG)	NUMBER OF BODIES OF EVIDENCE	AVERAGE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
C	SG1	10	550,538	358,165	65,05
	SG2	10	561,962	377,798	67,22
	SG3	10	557,02	344,67	61,87
	SG4	10	601,56	296,85	49,34
D	SG1	10	1083,88	225,17	20,77
	SG2	10	1109,17	133,19	12,00
	SG3	10	1102,92	198,25	17,97
	SG4	10	1054,24	190,47	18,06
E	SG1	10	1333,04	51,65	3,875
	SG2	10	1367,44	61,766	4,51
	SG3	10	1370,76	61,91	4,51
	SG4	10	1383,63	48,11	3,47
F	SG1	10	1394,22	56,74	4,069
	SG2	10	1370,08	61,22	4,468
	SG3	10	1387,01	51,51	3,719
	SG4	10	1418,64	100,27	7,068

Table 2. Microstrains values (με) obtained at each application point on miniconical abutments

APPLICATION POINT	STRAIN GAUGE(SG)	NUMBER OF BODIES OF EVIDENCE	AVERAGE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
C	SG1	10	500,02	340,578	68,11306
	SG2	10	507,21	369,96	72,93
	SG3	10	473,29	245,59	51,88
	SG4	10	517,34	289,25	55,912
D	SG1	10	1071,56	66,136	6,17
	SG2	10	1079,56	91,13	8,44
	SG3	10	1099,07	112,06	10,196
	SG4	10	978,25	187,36	19,15
E	SG1	10	1184,44	35,105	2,96
	SG2	10	1207,09	30,71	2,54
	SG3	10	1199,52	49,54	4,130
	SG4	10	1199,91	33,26	2,77
F	SG1	10	1302,82	74,29	5,70
	SG2	10	1334,21	64,43	4,82
	SG3	10	1354,44	47,52	3,50
	SG4	10	1369,68	52,43	3,82

Table 3. Microstrain values (με) and standard deviations obtained at each application point on the prosthetic abutments

APPLICATION POINT	CNM	Mini- abutment
C	567,77 με; ± 23,00	499,465 με; ± 18,84
D	1087,55 με; ± 24,67	1057,11 με; ± 53,82
E	1363,71 με; ± 21,61	1197,74 με; ± 9,52
F	1392,48 με; ± 20,15	1340,28 με; ± 28,89

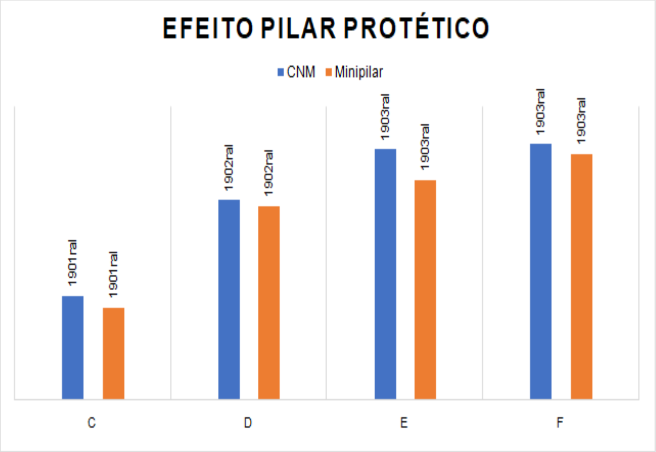

Figure 4. Microstrain mean values (μ) in relation to the prosthetic abutment effect

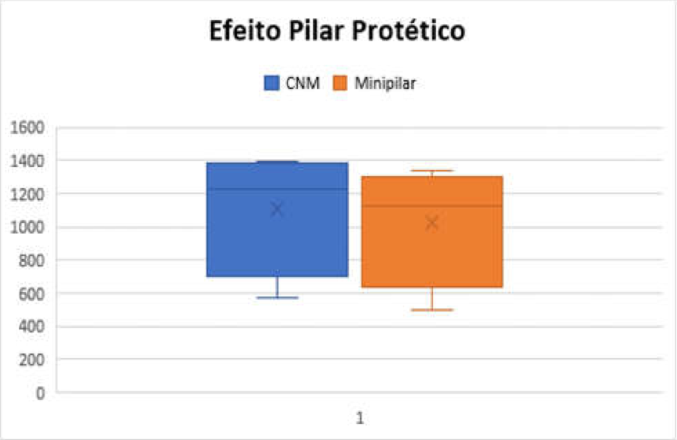

Figure 5. Box-plot plot of the distribution of microstrain values (μ) in relation to the prosthetic abutments

DISCUSSION

In this study, the biomechanical behavior of the prosthetic abutments under loads applied at certain points was observed, characterizing the microstrains captured by the strain gauges. The design, rigidity and geometric configuration of the prosthetic structure can influence the proper direction of these results. However, clinical success is directly linked to prosthetic abutments, screws and coping, which are subject to complex patterns of combination of horizontal, vertical and oblique forces [17]. The main methodologies to assess strains in laboratory models are photoelasticity, digital images correlation, mathematical models and strains gauge and, among them, SG has been widely used because it allows measurements of the surface deformations of a given material under static loading[18, 19]. This high accuracy for measuring the surface behavior of solids makes extensometry a very effective methodology in investigating the biomechanical behavior of implant-supported rehabilitations, since, in the case of two materials in contact with different mechanical properties (implant x bone), when the implant receives a load, these stresses will be transmitted in the region of its first contact, that is, on the surface of the supporting bone [20]. Currently, the finite element method (FEA) is a mathematical method responsible for numerous investigations of rehabilitative systems with osseointegrated implants[40;34].

However, the three-dimensional models used for such methodology allow its simplification, which can generate unreliable data[41]. The way to assess the accuracy of this method, that is, the way to validate these theoretical models is the verification of the compatibility of their results with laboratory experiments[35]. The use of strain gauge experiments to validate computational models is based on the technology used in their small diameter devices, which have a high precision to measure surface deformation [15]. According to Rangert, Jemt and Jorneus (1989), the functional activity of chewing induces vertical and oblique loads on the prosthetic structures and these loads are transferred from the prosthesis to the implant and finally to the bone. Faced with a functional load, different stress patterns are created as a function of the geometric configuration of the prostheses in question, both in the implant and in the bone, through the moment generated by the force, whose resulting tensions are absorbed in different degrees. If the tension resulting from the masticatory force is directed towards the long axis of the implant, the stress generated will be evenly distributed across the cross section of the implant (head) and the fixation threads. This will enable a high loading capacity for the implant and supporting bone. However, if the force acts in a transverse or oblique direction in relation to the long axis of the implant, the resulting tension will be generated from a flexion moment in the implant, with only a small portion of the cross section to contain the load and the bone will be loaded with high level of stress.

The force vectors that are axially directed to the implant are of a compressive nature; those with horizontal or oblique direction, on the other hand, may result in lateral displacement and the formation of torsional forces in the structure of the prosthesis, constituting leverage points or in tension and torque forces, which when excessive can cause failure in the structure of the prosthesis and bone-implant integration. Due to these aspects, many questions persist regarding the biomechanical behavior of all system components, whether they are related to the structure and materials used to make the prosthesis, as well as to the screws, pillars and the implant it self[11]. The satisfactory result of the treatment with integrated bone implant largely depends on the control of the incident loads. Excessive misdirected loads can cause high stresses and flexion moments that can induce bone resorption around the cervical region of the implant, loosening and fractured prosthetic components, which can lead to its failure [21,22,23]. The simulated occlusal load in this study was based on in vivo physiological loads observed in patients with implant-supported prostheses verified in the study by Mericske-Stern *et al*. (1995). In the literature, the loads used in SG analyzes ranged widely, from 30 to 300 N[9,10,11,12,13,14,23,24,25,26]. For the SG analysis, three episodes of load application were performed on the same specimen, a fact motivated by the high sensitivity inherent to microstrains records and associated with the high standard deviation of the averages of the resulting values. Strain gauges were positioned as performed in previous studies [9,10,11,12,13,14,23,24,25,26,36,37,38] in the cervical region tangent to the implants, seeking to record the microdeformation in the region of greatest stress concentration. When an implant is occlusal loaded, the stress is transferred to the bone, with the greatest concentration of stresses in the most coronal portion of the peri-implant bone tissue. This is a consequence of a general engineering principle which states that when two materials are in contact and one of them is loaded, stresses will be greatest where the materials have first contact [30]. The prosthetic design of CMN abutment was idealized to be used in a single prosthesis, due to its anti-rotational design. The use of copings without the anti-rotational system for casting in multiple prostheses could open another option for the use of this abutment. This fact was highlighted to carry out this research, it is the continuation of previous studies carried out by Scalzer Lopes et al., which applied axial loads. Analyzing the results described in tables 1 and 2, the smallest microstrain values were observed in the miniconical abutments. Observing table 3, the highest microstrain mean (1392.48 με; ± 20.15) was observed at application point F, in the CMN abutment and the lowest miscrostrain mean (499.465 με; ± 18.84) was observed at application point C, on the miniconical abutments. Although the CMN abutments had the highest microstrain values, all values found in this study are within the bone homeostasis range (between 100 με and 2000 με) presented in the study by Wiskott and Belser (1999), being considered physiologically accepted.

Observing table 3, the highest microstrains means (1392.48 με; ± 20.15) was observed at application point F, in the CMN abutment, and observing table 3, the highest microstrain mean in the miniconical abutment was also at the application point F (1340.28 με; ± 28.89). The application point F was incient on the buccal cusp tip of the second molar of the prosthesis, the results obtained at this point are in accordance with Misch (2006) who described several aspects related to implant prostheses. In the chapter on occlusal considerations, he mentioned that the angle of force in relation to the implant body can be influenced by the inclination of the cusp. Natural dentition always have steep, sloping cusps, and the 30° cusp angle has been restored to prosthetic teeth and natural tooth crowns. Larger cusp angles can incise food more easily and efficiently, yet occlusal contacts along the angled cusps result in angled loads to the crest bone. The magnitude of forces is minimized when the angled occlusal contact is not premature contact, but rather is a uniform load on a series of teeth or implants. However, angled cusp loading increases the resulting stress, with no observable benefits. Therefore, no advantage is gained, but the risk is increased. According to the test carried out, the load application point factor were statistically significant. The different load application points (C, D, E and F) presented different strain values around the implants. For PA C p-value: 0.14881695, for PA D p-value: 0.31952962, for PA E p-value: 0.000000000 and for PA F p-value: 0.00002103. The different load application points (C, D, E and F) presented similar microdeformation values around the implants. The results obtained are in euphony with Abreu *et al*., 2012. The results are in accordance with Scalzer Lopes (2021), since in his study the most peripheral load application points (points A and C), even though they are axial, it was possible to observe a higher concentration of stress and deformation in the structures closer to the loading regions, on the other hand, when the load was applied in a region closer to the center of the prosthesis (point B), the stresses and strains were distributed more evenly. In this study, it was observed that the farther the point of load application from the center of the prosthesis, the greater was the microstrain captured by the strain gauge in both prosthetic abutments. In descending order of microstrain: (Points C, Points D, Points E and Points F). In this study, in addition to SG, finite elements (FEA) were used and, therefore, the laboratory test confirmed the mathematical studies previously carried out. A fact that drew attention in the results obtained, as well as in the studies by Scalzer Lopes, was that there were no differences in these abutments, as the diameter of the CMN conical abutment (1.8mm) is greater than that of the mini-abutment (1.2mm). This fact should minimize microdeformations in the conical abutment. The null hypotheses of the work were not discarded, since the use of CMN abutments to support a three-element implant-supported prosthesis showed no difference in biomechanical behavior when compared to the use of miniconical abutments. The increase in the vertical component of the CMN abutment, that is, the height of 3.5 mm and the presence of an anti-rotational geometry, could suggest a higher concentration of tension (> 10%) and even greater peripheral bone deformation, since that these components in a multiple prosthesis could generate preload stresses caused by the mismatch between the prosthesis and the pillars or by the loss of passivity in their seating [33].

Conclusion

Therefore, it can be concluded from this research:

- Microstrains are similar for rehabilitation systems that used CMN or miniconical abutments;
- Microstrains are different for the load application points in both rehabilitation systems;
- Both groups of abutments have the highest stress peaks at the point of application in the most distal region of the dental element and at the cusp tip;

Abbreviations

3D = Three-dimensional
α = Level of significance
Cm = Centimeter
Kgf = Kilograms force
mm = Milimeter
n = Specimen number
N = Newton
Ncm = Newton centimeter
Ni-Cr = Nickel-chromium
MC = Miniconical
MPa = Megapascal
με = Microstrain
P = Probability value
SG = Strain gauge

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