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ORIGINAL ARTICLE

Overdenture retaining bar stress distribution: A finite-element analysis

CONRADO REINOLDES CAETANO[1], MARCELO FERRAZ MESQUITA[1], RAFAEL LEONARDO XEDIEK CONSANI[1], LOURENÇO CORRER-SOBRINHO[2] & MATEUS BERTOLINI FERNANDES DOS SANTOS[3]

[1]*Prosthesis and Periodontics,* [2]*Dental Materials Department, Piracicaba Dental School, State University of Campinas, Piracicaba, SP, Brazil, and* [3]*Restorative Dentistry Department, School of Dentistry, Federal University of Pelotas, Pelotas, RS, Brazil*

Abstract

Objective. Evaluate the stress distribution on the peri-implant bone tissue and prosthetic components of bar-clip retaining systems for overdentures presenting different implant inclinations, vertical misfit and framework material. ***Materials and methods.*** Three-dimensional models of a jaw and an overdenture retained by two implants and a bar-clip attachment were modeled using specific software (SolidWorks 2010). The studied variables were: latero-lateral inclination of one implant (–10°, –5°, 0°, +5°, +10°); vertical misfit on the other implant (50, 100, 200 μm); and framework material (Au type IV, Ag-Pd, Ti cp, Co-Cr). Solid models were imported into mechanical simulation software (ANSYS Workbench 11). All nodes on the bone's external surface were constrained and a displacement was applied to simulate the settling of the framework on the ill-fitted component. Von Mises stress for the prosthetic components and maximum principal stress to the bone tissue were evaluated. ***Results.*** The +10° inclination presented the worst biomechanical behavior, promoting the highest stress values on the bar framework and peri-implant bone tissue. The –5° group presented the lowest stress values on the prosthetic components and the lowest stress value on peri-implant bone tissue was observed in –10°. Increased vertical misfit caused an increase on the stress values in all evaluated structures. Stiffer framework materials caused a considerable stress increase in the framework itself, prosthetic screw of the fitted component and peri-implant bone tissue. ***Conclusions.*** Inclination of one implant associated with vertical misfit caused a relevant effect on the stress distribution in bar-clip retained overdentures. Different framework materials promoted increased levels of stress in all the evaluated structures.

Key Words: *finite element analysis, implant inclination, misfit, overdenture*

Introduction

Over the years, several developments in the field of health sciences have led to an increase in the life expectancy. However, despite the growth of elderly populations, many elderly patients present poor oral and general health conditions [1]. This fact means that the demand for prosthetic treatment will increase in the coming decades, even in countries with higher standards of dental care [2].

The most common treatment indicated for edentulous patients is the conventional complete denture [3]. However, there are other types of treatment that present better results for patient satisfaction with regard to aesthetics and function [4]. The use of dental implants is an important technique to overcome some limitations observed with conventional complete dentures, such as lack of retention and stability. Among implant rehabilitations, some authors consider overdentures the first treatment option for patients with a completely edentulous mandible [5,6]. Different retention systems are available for implant overdentures and a factor that must be considered is the inclination of the implants. Inadequate implant inclination could result in bigger numbers of recall appointments to change the retention system components or a prosthesis failure. The literature suggests that the maximum inclination between the implants for O'ring retainers is 10° [7]. When using magnets, the inclination of implants is not a limiting factor; nevertheless, this retention system presents a lower retention force and excessive wear of the magnets that can reduce patients' satisfaction [8,9]. A bar-clip

Correspondence: Mateus Bertolini Fernandes dos Santos, School of Dentistry, Federal University of Pelotas, 457 Rua Gonçalves Chaves, Pelotas, RS, Brazil, Zipcode: 96015-560. Tel: +55 19 2106 5200. E-mail: mateusbertolini@yahoo.com.br

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retaining system allows the correction of implants inclination due to bar framework waxing and casting. However, bars presenting misfits associated with excessive inclination of the implants can develop stresses that can overload the peri-implant bone tissue and prosthetic components, which can cause technical and biological complications [10,11].

Passive fit is extremely important and should be considered during the treatment, because its absence can cause complications in biological tissues, such as bone resorption, or mechanical failure of the prosthesis and implant systems, such as loosening or fracture of the screws, and fractures of the implant or bar framework.

Although several variables have been studied with respect to bar-clip retaining systems for overdentures, the influence of the inclination of the implants on the prosthesis biomechanics that presents vertical misfits has not yet been studied. The aim of this study was to evaluate, using three-dimensional (3-D) finite element analysis (FEA), the stress concentration on the peri-implant bone tissue and prosthetic components. For that, different inclinations for implants in the latero-lateral direction (–10°, –5°, 0°, +5°, +10°) and vertical misfit levels (50, 100 and 200 μm) were combined. Also, the influence of the bar framework material (type IV Au, Ag-Pd, Ti and Co-Cr) was evaluated.

Materials and methods

Three-dimensional solid models reproducing an anterior part of a severely re-absorbed jaw with two titanium implants (4.0-mm diameter ×11-mm length) and a bar-clip attachment system were modeled using specific 3-D modeling software (SolidWorks 2010, SolidWorks Corp., Concord, MA). Different latero-lateral inclinations of one implant generated a total of five 3-D models (–10°, –5°, 0°, +5°, +10°). The location of the misfit and the inclinations of the implant are shown in Figure 1.

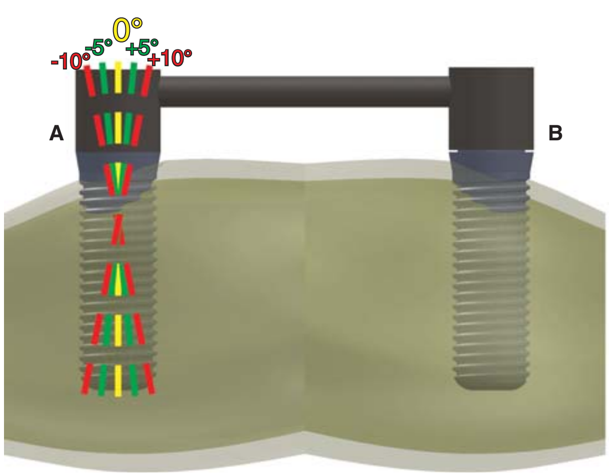

Figure 1. Geometric model used in the study. (A) Different evaluated inclinations; (B) Location of the vertical misfit.

Finite element models were obtained by importing the solid model into mechanical simulation software (ANSYS Workbench 11, Ansys Inc., Canonsburg, PE). The total numbers of nodes and elements generated in the FE models are presented in Table I. The shape of the element was tetrahedral with 10 nodes and the element size was 0.5 mm. Stability of the model was checked and the mesh was refined in the regions of interest.

The base of the mandible was set to be the fixed support and a displacement was applied to the ill-fitted component to simulate the elimination of the vertical misfit through tightening of the prosthetic screws. The analysis was made by means of von Mises stress for the prosthetic components and Maximum Principal stress for the bone tissue. Data were produced numerically, color coded and compared among the models. All materials used in the models were considered isotropic, homogeneous and linearly elastic. The elastic properties used were obtained from previous studies [12–14]. All the contacts between different materials were considered bonded.

Two FEA were carried out separately:

- Vertical misfit effect : Different levels of misfit (50, 100 and 200 μm) between bar and implant was evaluated for the different implant inclination groups (–10°, –5°, 0°, +5°, +10°), using Type IV gold (Au) as the bar material.
- Bar material effect : Different bar materials (Au, Co-Cr, Ag-Pd, Ti) were evaluated for the different implant inclination groups (–10°, –5°, 0°, +5°, +10°) in bars presenting 100 μm of vertical misfit.

Results

The inclination of one implant caused different effects for the analyzed structures. The +10° inclination presented the worst biomechanical behavior, presenting the highest values of von Mises stress on the bar framework and the highest values of tensile and compression stresses on the peri-implant bone tissue. Despite the parallelism between the implants on the 0° groups, the values observed in these groups were higher than those for groups presenting distal inclination (Table II).

Table I. Three-dimensional models specifications.

Inclination	Nodes	Elements
–10°	950.440	592.786
–5°	866.198	541.633
0°	857.744	536.289
+5°	856.237	534.924
+10°	853.133	532.830

Table II. Von Mises stress values (MPa) for bar framework and prosthetic screw of the fitted component and Maximum Principal Stress values (MPa) for peri-implant bone tissue for different latero-lateral inclinations and misfit levels in the gold (Au type IV) bar framework groups.

				Peri-implant bone tissue	
Inclination	Misfit (µm)	Bar framework	Prosthetic screw	Tensile	Compression
–10°	50	89.45	4.81	2.54	0.79
	100	178.90	9.62	5.08	1.58
	200	357.80	19.24	10.16	3.15
–5°	50	75.50	4.69	2.67	0.93
	100	151.00	9.37	5.35	1.87
	200	302.00	18.75	10.69	3.74
0°	50	97.00	5.14	3.26	1.91
	100	193.99	10.28	6.51	3.81
	200	387.99	20.56	13.02	7.63
+5°	50	93.80	7.75	3.22	1.26
	100	187.60	15.51	6.43	2.53
	200	375.19	31.02	12.87	5.05
+10°	50	113.15	7.12	3.78	2.06
	100	226.29	14.25	7.56	4.11
	200	452.59	28.49	15.12	8.23

* Compressive load was characterized by negative values of Maximum Principal Stress.

It is also possible to observe that the increase of the vertical misfit level caused increased stress values in all the analyzed structures (Table II). Different bar framework materials presented a relevant influence on the stress distribution for the prosthetic components and peri-implant bone tissue, when the stiffer material induced the highest values of stress in all analyzed structures. Type IV gold alloy presented the lowest stress values in all components, while the Co-Cr alloy showed the highest values of stress in all the analyzed structures and simulations (Table III).

Discussion

The present study evaluated the influence of implant inclination associated with vertical misfit on the stress distribution on peri-implant bone tissue and prosthetic components of a bar-clip attachment system retained by two implants. It is possible to observe that the bigger inclination (10°) presented the highest values of stress for both bar framework and peri-implant bone tissue. The highest value of stress in the prosthetic screw was found in the +5° group. Based on these results, it is possible to suggest that the mesial inclination of the implant leads to an unfavorable biomechanical situation, amplifying the stresses in all the studied components and tissues, which could result in peri-implant bone resorption or failure of the prosthetic components [15–17].

The opposite was also observed, since the implants presenting distal inclination showed the lower values of stress in the bar framework and prosthetic components (–5° group) and peri-implant bone tissue (–10° group), when the group with implants parallel between them presented average stress values. These findings could be considered in agreement with previous studies [18–20], which advocates that the distal inclination of implants improve the biomechanical behavior of full-arch rehabilitations compared to parallel implants, by increasing the contact surface area and reducing the cantilever length of the prosthesis. However, it is important to highlight that bar-clip attachment systems for overdentures do not present cantilevers. However, the improvement in the biomechanical performance could be attributed only to the distal inclination of the implant.

The level of misfit also influenced the stress values in all the studied regions, where a direct relationship was observed between an increase of the misfit and increase of the stress values for all analyzed situations. It has been claimed that prosthetic components and peri-implant bone under high levels of stress are more prone to screw loosening, fractures or bone resorption [15–17].

With regard to the different framework materials, the cobalt-chromium alloy induced the highest values of stress in all studied regions and situations. A relationship between stiffness of the materials and stress values was found in the current study, when stiffer materials promoted an increase on the stress values. These findings are in agreement with previous studies evaluating the influence of different framework materials and presence of misfit on three-dimensional stress distribution in the overdenture-retaining bar system [12,21,22].

Table III. Von Mises stress values (MPa) for bar framework and prosthetic screw of the fitted component and Maximum Principal Stress values (MPa) for peri-implant bone tissue for different latero-lateral inclinations and bar framework material presenting 100 μm of vertical misfit.

				Peri-implant bone tissue	
Inclination	Material	Bar framework	Prosthetic screw	Tensile	Compression
–10°	Au	178.90	9.62	5.08	1.58
	Ag-Pd	211.83	10.27	6.00	1.86
	Ti	248.63	10.58	6.87	2.13
	Co-Cr	475.40	13.05	13.21	4.10
–5°	Au	151.00	9.37	5.35	1.87
	Ag-Pd	178.21	10.83	6.31	2.21
	Ti	208.63	12.28	7.22	2.52
	Co-Cr	389.77	21.29	13.83	4.86
0°	Au	193.99	10.28	6.51	3.81
	Ag-Pd	228.77	11.82	7.68	4.51
	Ti	268.20	13.31	8.79	5.17
	Co-Cr	497.37	22.84	16.77	9.97
+5°	Au	187.60	15.51	6.43	2.53
	Ag-Pd	221.12	17.78	7.59	2.98
	Ti	257.00	19.94	8.68	3.41
	Co-Cr	478.95	34.01	16.51	6.51
+10°	Au	226.29	14.25	7.56	4.11
	Ag-Pd	266.63	16.28	8.91	4.86
	Ti	308.96	18.21	10.19	5.55
	Co-Cr	575.61	30.64	19.31	10.60

* Compressive load was characterized by negative values of Maximum Principal Stress.

The FEA method has been extensively used in dentistry due to its ability to evaluate the stress distribution in inner regions of prosthetic components and bone tissue [12,15,19,22–24]. However, it presents some limitations that should be addressed. All the materials adopted in this study are considered homogeneous, with linear elasticity and isotropic behavior; however, it is known that the bone tissue is not homogeneous and presents anisotropic behavior [25]. The contact of the different parts of the finite element model was considered to be bonded among all the components. The osseointegrated implant was considered as bonded; however, 100% of contact between these parts is not observed clinically [26].

In addition, the capability of the bone to adapt when submitted to stress is not fully represented in this mathematical method. The comparison of the increased relationship among the stress values and different levels of misfit should be interpreted with caution because a linear FEA was accomplished, thus the results were also presented with a linear pattern.

To date, there is no exact stress value that can be directly related to any clinical implication. However, the comparison of results among the different groups can surely be used by professionals to consider whether or not a certain kind of therapy or material should be used. The present findings shows that mesial inclination of one implant increases the stress values on the peri-implant bone tissue and prosthetic screw, which, for this reason, should be taken into account during the surgical planning of the implants. In regard to the misfit, it is well known that the best fit possible should be pursued by the professional during the clinical practice to obtain longevity of the treatment [27]. Also, this study and previous ones [14,21,22] report that the stress values increased in a direct relationship with the misfit level. Thus, the presence of clinically detectable misfit should be avoided and, when it is detected, the professional must consider methods to reduce framework misfit, such as soldering [28]. Cobalt-chromium frameworks induced higher stress values in the framework itself and in the peri-implant bone tissue and prosthetic screw, when compared to other materials (Au type IV, Ag-Pd and Ti). Hence, when it is possible, the professional should avoid the use of cobalt-chromium alloy for overdenture frameworks, in order to create a clinical situation that induces lower stress to the peri-implant bone tissue and overdenture retaining system. Further studies should be made to evaluate the influence of the inclination of the implant in clinical situations. FEA studies evaluating the inclination of both implants and overcoming the presented limitations, such as the use of frictional coefficient between the prosthetic components and the anisotropic properties of the bone tissue, are also suggested. Also, the role of masticatory function on the stress distribution in the overdenture-retaining bar system should be evaluated [14].

Within the limitations of this study, it is possible to conclude that (1) the mesial inclination of the implant caused an increase in the stress in all components, where the higher inclination (10°) caused the highest values with the exception of the prosthetic screw; (2) the distal inclination of the implants decreased the stress values when compared to the control group (both implants parallel); and (3) higher misfits and stiffness of the bar framework increased the stress values in all studied regions.

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