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Implant Inclination and Horizontal Misfit in Metallic Bar Framework of Overdentures: Analysis By 3D-FEA Method

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The aim of this study was to evaluate by three-dimensional finite element analysis (3D-FEA) the biomechanics involved in bar-framework system for overdentures. The studied factors were latero-lateral angulation in the right implant (-10, -5, 0, 5 and 10 degrees), and different bar cross-sections (circular, Hader and oval) presenting horizontal misfits (50 or 150 µm) on the opposite implant. Positive angulation (5 and 10 degrees) for implant inclination to mesial position, negative angulation (-5 and -10 degrees) for distal position, and zero degree for parallel implants. The von Mises stresses evaluated the bar, screw and the implant; maximum principal, minimum principal and shear stress analyses evaluated the peri-implant bone tissue. Parallel implants provide lower stress in alveolar bone tissue; mesial inclined bars showed the most negative effect on prosthetic structures and implants. In conclusion, bar cross-section showed no influence on stress distribution for peri-implant bone tissue, and circular bar provided better behavior to the prosthetic system. Higher stress concentration is provided to all system as the misfit increases.

Key Words: dental implants. overdentures. finite element analysis. misfit.

Introduction

Rehabilitations associated to osseointegrated dental implants have been pointed as the best treatment choice for edentulous patients. Overdentures retained by two implants have been indicated as the minimum treatment to offer to edentulous patients (1,2). This procedure stands out for having relatively lower cost when compared to fixed dentures (3) and superior results to conventional denture in various aspects, such as patient satisfaction, comfort, chewing ability, social activities, and quality of life (4).

Different retaining systems for overdentures have been reported in the literature with satisfactory clinical results (5). Some of the commercially available retaining systems for overdentures are: O'ring attachment, bar-clip system, locators and telescopic crowns (6–8). The bar-clip system provides greater retention and better long-term stability and comfort among them (8). Therefore, bar-clip system has some biomechanical advantages due to the splinting of the implants, allowing better force distribution to all retaining components (9).

Another significant factor is that the angulation between two implants, and between each implant and reference planes did not appear to affect prosthesis maintenance, while individual implants with lingual inclination > or = 6 degrees, and facial inclination < 6.5 degrees is associated with the prosthesis repairs. In addition, no significant relationships were found between number of adjustments and repairs and inter-implant angles; however, when the lingual inclination of an implant is > or = 6.0 degrees or the facial inclination is < 6.5 degrees there was a significantly higher number of repairs (10). Moreover, the absence of parallelism between the implants is common in clinical practice because the implant position is dependent of the factors alveolar bone amount, anatomical characteristics, and might be also influenced by the experience of the professional (10).

When implants show some angulation discrepancy between them, the bar-clip system is indicated since the presence of a greater angulation may increase the wear of components in other systems (as replacement of the O'ring retentive system). In addition, no significant relationships were shown between number of adjustments or repairs and inter-implant angles; however, when the lingual inclination of an implant is > or = 6.0 degrees or the facial inclination is < 6.5 degrees there was a significantly higher number of repairs (10).

Some different configurations of bar cross-section were available in several studies, and sections such as oval, circular and Hader have shown different stress distribution to the components. Three-dimensional models of a severely resorbed mandibular arch with overdenture retained by two implants, and a bar-clip attachment system with different bar framework sections, clip materials, and vertical misfit of 100 µm showed that different clip materials and cross sections of the bar framework influenced the stress distribution at peri-implant bone tissue (11).

Due to linear and volumetric alterations of materials used for the metal alloy castings, conventional lost wax casting technique to cast one-piece full arch implant frameworks is imprecise in relation to the passive fit requirements because distortions may occur in the bar geometry. Thus, the consequences for the osseointegration of the implant supported prosthesis with misfit screws are always under investigations (12).

Because osseointegrated implants have no resilience in bone, passive fit has been identified from biologic and mechanical aspects. Distortion of the metal framework is commonly cited as the main cause of misfit, and ill-fitting bars induce higher levels of stress which are transmitted to the implant and peri-implant bone tissue (13).

Stresses caused by tensile, compressive or bending forces induced in the bar, screws, implants and peri-implant bone may cause damage to the prosthetic components, as well as biological complications such as marginal bone loss and implant loss. Misfit influences the pattern and magnitude of stress distribution in the prosthesis, implant components, and surrounding alveolar bone, and the stress increased in each component ranged from 8% to 64% (14).

As aforementioned, some variables related to overdenture bar-clip retaining system have been studied, and the results are controversial in different works. However, the influence of different implant inclinations and bar geometries on biomechanics of prosthesis supported by implants with different levels of horizontal misfit has not been sufficiently well clarified.

Therefore, the aim of this study was to evaluate, using 3-D FEA (Three-dimensional finite elements analysis), the influence of (1) bar cross-section geometry (circular, oval, and Hader) with two different simulated horizontal misfits (50 and 150 µm); and (2) different angulations between implants (-10, -5, 0, 5 and 10 degrees) in overdenture-retaining bar system with two implants. The hypothesis tested in this study was that different bar cross-section geometries, different horizontal misfits and different implant angulations would promote different stress concentrations in overdenture supported by two implants.

Material and Methods

Three-dimensional solid structures were modeled reproducing anterior part of an edentulous mandible with two external hexagon titanium implants (4.1-mm diameter x 11.5-mm length), distant 18 mm from each other. The distance was based on previous studies in the literature, which states 18 mm as an ideal distance for the bar-clip system (11,15). The bone dimensions were the following: 11-mm buccolingual width, 29-mm mesiodistal length, 14.5-mm of height, and cortical bone with 0.5-mm thickness, meaning a Class V reabsorbed mandible (16).

Three different overdenture-retaining bar systems (circular, ovoid, and Hader) were built on the osseointegrated implants. The dimensions of the bar framework were the following: circular bar presented 2-mm diameter; ovoid bar presented 2.5-mm height and 2-mm diameter in the central part; and Hader bar presented 2.5-mm height, 2-mm diameter in circular superior part. All parts were modeled using 3-D software (SolidWorks 2010; SolidWorks Corp., Concord, MA, USA), according previous study (11).

Finite element (FE) models were obtained by importing the solid model into mechanical simulation software (ANSYS Workbench 14; Ansys Inc., Canonsburg, PA, USA.). All materials used in the models were considered isotropic, homogeneous and linearly elastic. The elastic properties used (Table 1) were taken from literature (17-19). The elements used were tetrahedral with 10 nodes and maximum size of 0.5 mm. The total of elements generated for the FE models

Table 1 - Material properties

Material	Young's modulus (GPa)	Poisson's ratio	Authors
Cortical bone	13.7	0.3	Ref 17
Cancellous bone	1.37	0.3	Ref 17
Titanium (Bar and screw)	110	0.28	Ref 19
Titanium (Implant)	110	0.33	Ref 18

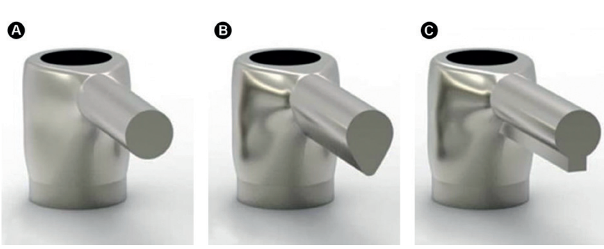

Figure 1. Bar cross-section geometries: Circular (A), Oval (B) and Hader (C).

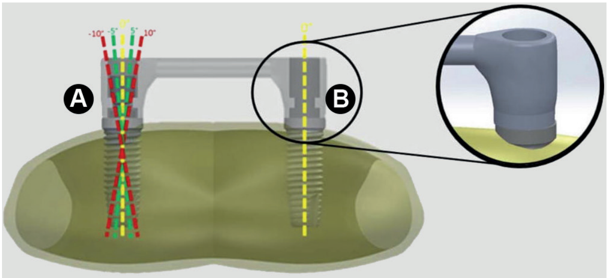

Figure 2 - Geometric model used. (A) Different inclinations evaluated; (B) Location of the horizontal misfit.

ranged in a scale from 382,332 to 564,833; and for total nodes the scale ranged from 571,933 to 837,651.

Circular, ovoid and Hader bar cross-section geometries were built in each model (Fig. 1). To simulate the misfit closure promoted in clinical practice by the tightening of the retaining screws, two horizontal displacements of 50 and 150 µm were applied on the implant B (right end of the metallic bar) in the mesio-distal direction. The misfit may occur in the metallic bar due to the lost wax casting method to be considered inaccurate in relation to the passive fit requirement (12). Five models were created varying the latero-lateral implants inclination (-10, -5, 0, 5, 10 degrees), as shown in Figure 2.

The FE analysis was made by means of numerical data and color gradient examination. Von Mises stresses were used to evaluate the bar, screw and implant while maximum and minimum principal stresses and shear stress were obtained to evaluate the peri-implant bone tissue behavior.

Results

Qualitative analyses for von Mises stresses in the mechanical part of the models are shown in Figure 3. Stresses were concentrated along the bar and at the joint between bar and abutment. Prosthetic screw showed stress concentration in the first third. The implant showed higher stress at the platform and at the first steps of screw threads. Qualitative Principal stress and shear stress in the peri-implant bone tissue are shown in Figure 4. The stresses were concentrated at the cervical third of the implant around the peri-implant alveolar bone.

Implant Angulation Influence

The influence of implant inclination on bone tissue is shown in Figure 5. In general, the Minimum Principal stress at bone tissue has shown relevant higher values for implants mesially angulated, ranging from 14% higher (circular) to 42% (oval and Hader) in 5 degrees implants and ~ 38% for 10 degrees, regardless of bar cross section. The -10 degrees distally angulated showed stress ~ 45% higher.

The smaller distal inclination (-5 degrees) showed no relevant influence. However, the opposite was observed for Maximum Principal Stress evaluation, as the 5 degrees distally (-5 degrees) implant angulation presented the only relevant higher value compared with parallel implants (~33%). Implant inclination at both direction and degrees showed a relevant increase in Maximum Shear stress (~ 51% for -5 degrees and ~ 63% for -10 degrees), with slight higher values for distally inclined implants compared

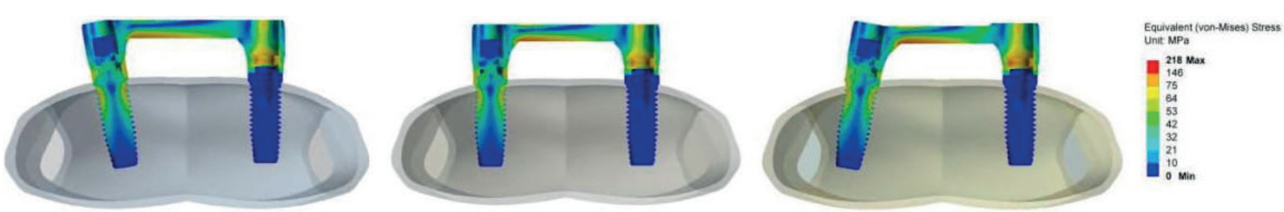

Figure 3. Representative von Mises stresses in bar framework, prosthetic screw and implant. 50 µm misfit model, circular bar cross-section and -10, 0 and +10 inclinations.

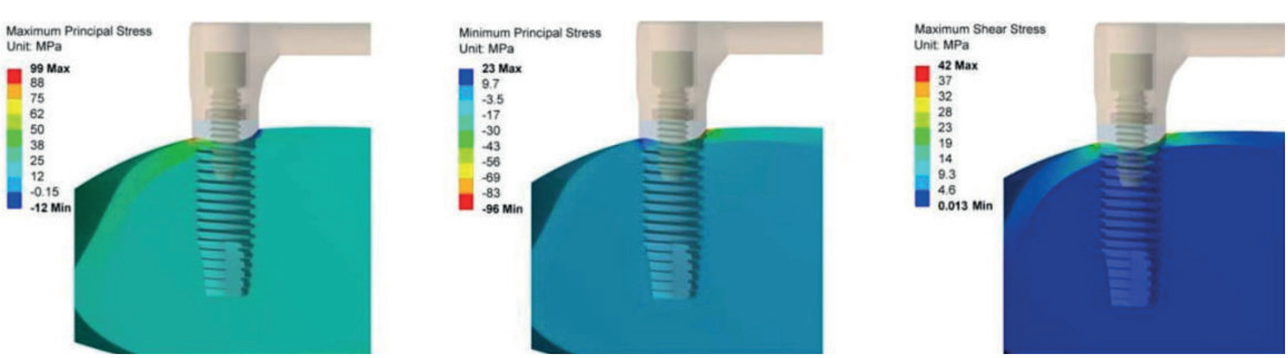

Figure 4. Qualitative analysis in peri-implant bone. Principal and shear stresses.

with mesially ones (~ 27% for 5 degrees and ~ 41% for 10 degrees).

For prosthetic components, parallel and distally angulated implants have shown similar and lower von Mises stresses at the implant structure between the two misfit conditions (Fig. 6). A relevant lower stress concentration was observed in the framework structure (~ -7%) and retention screw (~ -18%) for distally angulated implants. Parallel implants (zero degree, considered as angulation pattern) presented better behavior than mesially angulated ones (~21%). In general, mesial angulated implants provided higher stress concentration for all prosthetic structures.

Bar Cross-Section Influence

Bar cross-section showed no relevant influence on tensile, compressive and shear stress values in peri-implant bone tissue (Figs. 5 and 6). Generally, circular bar framework presented lower internal von Mises stresses than oval and Hader frameworks and led to lower stress concentration in the retention screw. No conclusive influence was observed on the bar cross-section effect on the implants (Fig. 6).

Horizontal Misfit Effect

The increase of horizontal misfit from 50 to 100 µm led to relevant higher stress for all models when the compressive, tensile and shear stresses (Fig. 5) and implant inclination (Fig. 6) were considered.

Discussion

Misfit has been characterized as responsible to provide

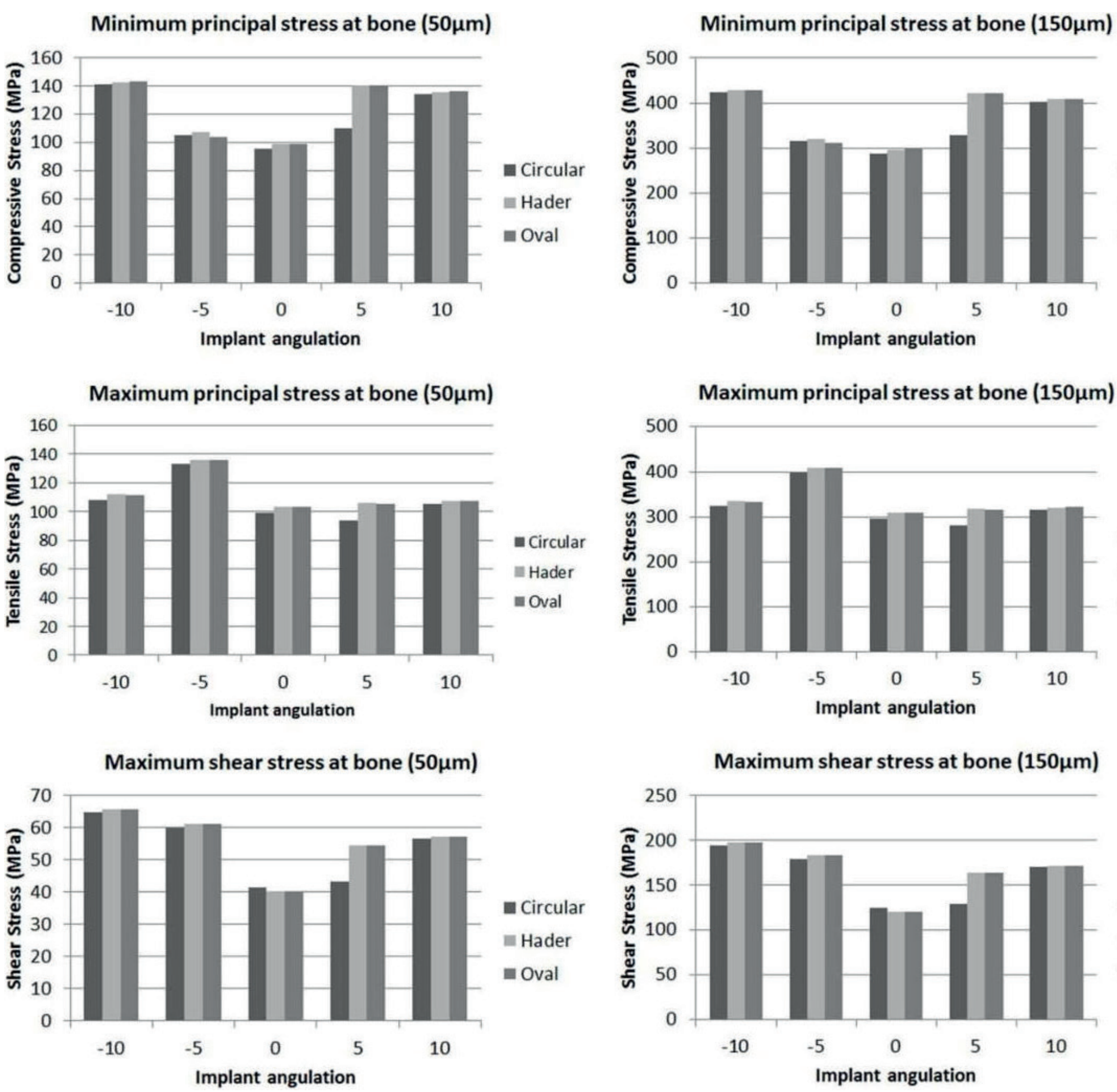

Figure 5. Principal and shear stresses results in the peri-implant bone tissue.

contact asymmetry between the prosthetic components, causing increased tension in the retaining system components and supporting bone tissue (20). The current study has shown that the increase of the horizontal misfit is directly related to the stress increase generated across the entire system (bar framework, prosthetic screw, implant and alveolar bone tissue), which is in agreement with a previous study (21). When compared to the vertical misfit, the findings suggest that horizontal misfits may be more prejudicial for splinted implants. It has been alleged that the amplification of vertical misfit seems to influence the stress distribution on the bar framework, while on the peri-implant bone tissue the increase in the stress levels was not considerable (22). The high levels of stress have been responsible by the screw loosening, component fractures and bone resorption (14,23). A previous study about fitting accuracy of implant/prosthetic framework showed that the conventional casting technique presents a mean value of horizontal misfit of 49.2 µm and might achieve a maximum value of 134.8 µm (24), being these misfit values adapted in the current investigation.

Mesially implant angulation showed higher stress values in the prosthetic components. When the implant is mesially inclined, the bar is shorter than in the parallel or distal implant, and may reduce the stress absorption into the bar structure and to cause greater stress to the support components (retention screw and implant) and into the metallic bar. Based on these results, it can be suggested that the mesial angulation of the implant leads to some unfavorable biomechanics, more favorable to cause failures

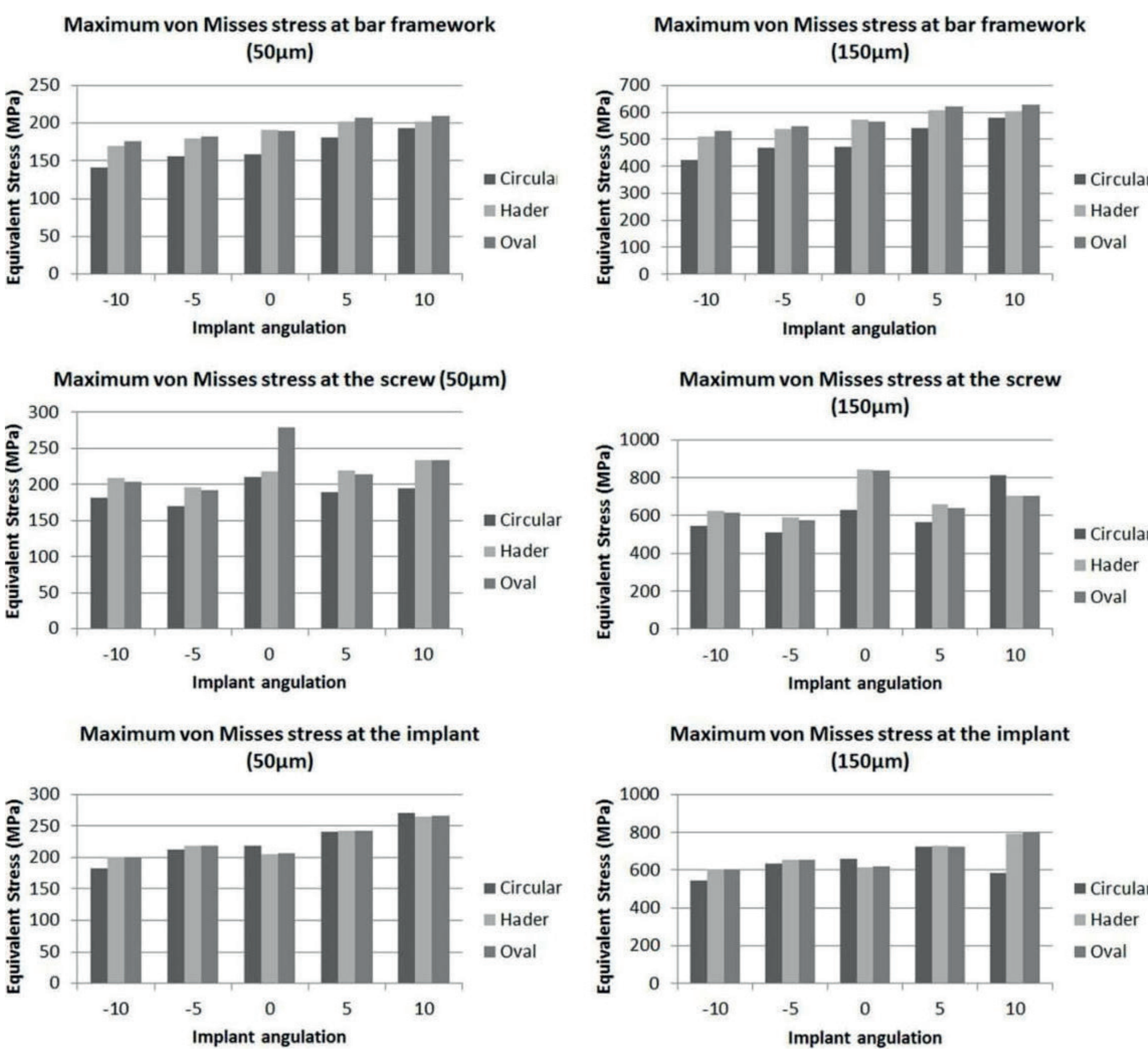

Figure 6. von Mises stresses results in the framework, screw and implant.

of the prosthetic components.

These results are in agreement with a previous study (22). The opposite can be observed for distal inclination, in which lower stress values were observed for prosthetic components when compared to the mesial positioning. The longer bar used in this condition might have provided better stress distribution. Considering these results, the study hypothesis that different bar cross-section geometries, different horizontal misfits and different implant angulations would promote different stress concentrations in overdenture supported by two implants was accepted.

In addition, in the distal angulation the loads will be better directed to the long axis of the implant than in the mesial angulation. Parallel implants (zero degree, considered as inclination pattern) presented lower stress values for compressive, tensile and shear in peri-implant bone tissue due to more uniform stress distribution around the implant. The results suggest that parallel implants present better biomechanical behavior than non-parallel ones, even those with small misalignments (± 5 degrees). The results obtained in the analysis of the bone tissue did not show clear information on what would be the less dangerous inclination of the implant when the parallelism is not possible.

Regarding to bar cross-section, the circular geometry showed lower stress values at the bar framework and screw. Oval and Hader cross-sections did not differ in the stress distribution to the prosthetic components; however, both provided slight higher stress than circular one. It is possible to observe that oval and Hader bars show greater cross-sectional area than circular one (Fig. 1). The dimension is the same in the horizontal plane but oval and Hader are wider in the vertical plane. By this reason, this geometry causes more rigidity in both configurations, which provides more stress concentration into the metallic bar. Circular bar geometry provided lower stress in the retention screw (~14%). It is possible to agree that the higher rigidity of Hader and oval bars promote also higher stress in the fixation screws (25).

However, different bar cross-sections did not influence the stress at the alveolar bone tissue and implants. The literature has shown that the viscoelastic properties of bone tissue are able to overcome the influence of the framework material on the stress concentration (25). Besides the cross-section did not influence the stress concentration at bone tissue in the current study, and another FEA study showed that circular bar shows more favorable biomechanical behavior for ill-fitted frameworks during occlusal loading, inducing less micro-strain on peri-implant tissue and less stress on the clip and prosthetic screws of the ill-fitted component (11).

The outcomes of this study demonstrated that the increase of the horizontal misfit and implant angulation have considerable influence on the stress levels in the peri-implant alveolar bone tissues, which was also observed by previous FEA reports (21,22). Nevertheless, clinical studies should be done to understand the level of stress tolerance of the peri-implant bone tissue and its clinical implication.

The results of this study allow to conclude that (1) Parallel implants showed lower stress values for peri-implant bone tissue than mesial inclined implants; (2) Different bar cross-sections did not influence the stress values in the peri-implant bone tissue, and oval and Hader geometries induced higher stress values in the prosthetic components; and (3) Increased horizontal misfit promoted higher stress values.

Resumo

O objetivo neste estudo foi avaliar por meio do método por elemento finito tridimensional (3D-AEF) a biomecânica envolvida na infraestrutura do sistema barra-clipe para *overdentures*. Os fatores de estudo foram inclinação mésio-distal entre implantes (-10, -5, 0, 5, 10 graus) e diferentes seções transversais da barra metálica (circular, oval e Hader) com desajuste horizontal (50 e 150 µm). Valores de inclinação positivas (5 e 10 graus) indicam inclinação do implante para mesial e valores negativos (-5 e -10 graus) mostram inclinação para distal, enquanto zero grau indica implantes paralelos. Valores de tensões equivalentes de von Mises foram utilizadas nos sistemas barra, parafuso e implante. Tensão máxima e mínima principal, e cisalhante foram utilizadas para análise do osso alveolar peri-implante. Implantes paralelos promoveram menores tensões em tecido peri-implante; as inclinações para mesial apresentaram piores resultados para as estruturas protéticas e implantes. As diferentes seções transversais da barra não mostraram influência na distribuição de tensões no osso alveolar peri-implante. Concluindo, a barra circular apresentou melhores resultados para os componentes protéticos e maiores valores de tensões foram observados em todos os modelos na medida que o desajuste aumentou.

References

1. Thomason JM. The use of mandibular implant-retained overdentures improve patient satisfaction and quality of life. J Evid Based Dent Pract 2010;12 (3 Suppl):182–4.
2. Thomason JM, Feine J, Exley C, Moynihan P, Müller F, Naert I, et al. Mandibular two implant-supported overdentures as the first choice standard of care for edentulous patients--the York Consensus Statement. Br Dent J 2009;207:185–186.
3. Carlsson GE, Omar R. The future of complete dentures in oral rehabilitation. A critical review. J Oral Rehabil 2010;37:143–156.
4. Awad MA, Lund JP, Shapiro SH, Locker D, Klemetti E, Chehade A, et al. Oral health status and treatment satisfaction with mandibular implant overdentures and conventional dentures: a randomized clinical trial in a senior population. Int J Prosthodont 2003;16:390–396.
5. Heschl A, Payer M, Clar V, Stopper M, Wegscheider W, Lorenzoni M. Overdentures in the Edentulous Mandible Supported by Implants and Retained by a Dolder Bar: A 5-Year Prospective Study. Clin Implant Dent Relat Res 2013;15:589–599.
6. Ha S-R, Kim S-H, Song S-I, Hong S-T, Kim G-Y. Implant-supported overdenture with prefabricated bar attachment system in mandibular edentulous patient. J Adv Prosthodont 2012;4:254.
7. Deslis A, Hasan I, Bourauel C, Bayer S, Stark H, Keilig L. Numerical investigations of the loading behaviour of a prefabricated non-rigid bar system. Ann Anat - Anat Anzeiger. Elsevier GmbH 2012;194:538–544.
8. Trakas T, Michalakis K, Kang K, Hirayama H. Attachment Systems for

Implant Retained Overdentures: A Literature Review. Implant Dent 15:24–34.
9. Ueda T, Kremer U, Katsoulis J, Mericske-Stern R. Long-term results of mandibular implants supporting an overdenture: implant survival, failures, and crestal bone level changes. Int J Oral Maxillofac Implants 2011;26:365–372.
10. Walton JN, Huizinga SC, Peck CC. Implant angulation: a measurement technique, implant overdenture maintenance, and the influence of surgical experience. Int J Prosthodont 2001;14:523–530.
11. dos Santos M, Bacchi A, Correr-Sobrinho L, Consani R. The Influence of Clip Material and Cross Sections of the Bar Framework Associated with Vertical Misfit on Stress Distribution in Implant-Retained Overdentures. Int J Prosthodont 2014;27:26–32.
12. Carr AB, Stewart RB. Full-arch implant framework casting accuracy: preliminary in vitro observation for in vivo testing. J Prosthodont 1993;2:2–8.
13. Helldén LB, Dérand T. Description and evaluation of a simplified method to achieve passive fit between cast titanium frameworks and implants. Int J Oral Maxillofac Implants 2000;13:190–196.
14. Kunavisarut C, Lang LA, Stoner BR, Felton DA. Finite element analysis on dental implant - supported prostheses without passive fit. J Prosthodont 2002;11:30–40.
15. dos Santos MBF, Caldas RA, Zen BM, Bacchi A, Correr-Sobrinho L. Adaptation of overdenture-bars casted in different metals and their influence on the stress distribution—A laboratory and 3D FEA. J Biomech 2015;48:8–13.
16. Cawood JI, Howell RA. A classification of the edentulous jaws. Int J Oral Maxillofac Surg 1988;17:232–6.
17. Abu-Hammad OA, Harrison A, Williams D. The effect of a hydroxyapatite-reinforced polyethylene stress distributor in a dental implant on compressive stress levels in surrounding bone. Int J Oral Maxillofac Implants 2000;15:559–564.
18. Korioth TWP, Johann AR. Influence of mandibular superstructure shape on implant stresses during simulated posterior biting. J Prosthet Dent 1999;82:67–72.
19. Sakaguchi RL, Borgersen SE. Nonlinear finite element contact analysis of dental implant components. Int J Oral Maxillofac Implants 1993;8:655–661.
20. Bacchi A, Consani RLX, Mesquita MF, dos Santos MBF. Stress distribution in fixed-partial prosthesis and peri-implant bone tissue with different framework materials and vertical misfit levels: a three-dimensional finite element analysis. J Oral Sci 2013;55:239–244.
21. Spazzin AO, dos Santos MBF, Sobrinho LC, Consani RLX, Mesquita MF. Effects of Horizontal Misfit and Bar Framework Material on the Stress Distribution of an Overdenture-Retaining Bar System: A 3D Finite Element Analysis. J Prosthodont 2011;20:517–522.
22. Caetano CR, Mesquita MF, Consani RLX, Correr-Sobrinho L, Dos Santos MBF. Overdenture retaining bar stress distribution: A finite-element analysis. Acta Odontol Scand 2015;73:274–279.
23. Natali AN, Pavan PG, Ruggero AL. Evaluation of stress induced in peri-implant bone tissue by misfit in multi-implant prosthesis. Dent Mater 2006;22:388–395.
24. Al-Fadda SA, Zarb GA, Finer Y. A comparison of the accuracy of fit of 2 methods for fabricating implant-prosthodontic frameworks. Int J Prosthodont 2007;20:125–131.
25. Bacchi A, Consani RLX, Mesquita MF, dos Santos MBF. Effect of framework material and vertical misfit on stress distribution in implant-supported partial prosthesis under load application: 3-D finite element analysis. Acta Odontol Scand 2013;71:1243–1249.

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