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Research Article

Effect of Aligned Implants on The Stress in Partial Fixed Prosthesis Submitted To Axial or Oblique Loads Exerted on The Molar: A Photoelastic Study -

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ABSTRACT

Objective: The aim of this study was to verify the effect of aligned implants on the stress in partial fixed prosthesis submitted to axial or oblique loads.

Methods: A photoelastic model was made for each implant type (EH - external hexagon, IH - internal hexagon, and MT - Morse taper) in which were placed three aligned implants and a Ni-Cr framework with three units. The prostheses were subjected to axial (AL) or oblique (OL) loads of 100 N applied at first molar. A polariscope analyzed the photoelastic behavior of the models with Fringes software in Matlab platform.

Results: Qualitative analysis: EH/AL - Greater stress on the implant apexes of the second premolar and first molar, and lower intensity on second molar; IH/AL - Similar stress at the implant apexes of the first and second molars, and larger intensity at the second premolar; MT/AL - Higher stress with different concentrations at regions of the implants; EH/OL - Lower stress intensity at the apexes of the second molar and second premolar when compared to first molar; IH/OL - Stress with similar intensity at implant apexes; and MT/OL - Greater stress at the second molar, and smaller at the first molar and second premolar. Quantitative analyses: EH/AL (T=15.32 and Nf=1.53, IH/AL (T=13.29 and Nf=1.32), MT/AL (T=15.29 and Nf=1.52), EH/OL (T=15.29 and Nf=1.52, IH/OL (T=14.15 and Nf=1.41), and MT/OL (T=17.08 and Nf=1.70). Conclusions: Aligned implants in partial fixed prosthesis promoted different stresses when the first molar was submitted to axial or oblique loads.

Keywords: Dental Implant; Partial Fixed Prosthesis; Photoelastic Analysis; Induced Stress

INTRODUCTION

Changes in the design of the implants, improved biomaterials and better surgical techniques have enhanced the clinical success of implant-supported prostheses, and patient's satisfaction in long-term. This fact has also been associated to aesthetic because no soft tissue recession was observed in either cement- or screw-retained crowns up to three years post-loading. In addition, esthetic fulfillment survey revealed that patients did not have a preference for crown type; however, dentists favored cement-retained over screw-retained treatments [1].

Biomechanical aspects of the osseointegrated implant is different from those that occur in natural tooth. Force distribution with natural teeth depends on micromovement induced by the periodontal ligament, and the location and cusp inclination of the tooth qualitatively alter the force pattern. Moreover, osseointegrated implants have not micromovements associated with force distribution, and the osseointegrated implant interface is completely different from the natural tooth. Alterations in tooth location and cusp inclination are suggested to limit the implant overload [2].

Another important factor is the effect of the load location on the resulting stress. Vertical loading at single location results in high stress values in the alveolar bone and implant. Besides that, with loading at 2 or 3 locations the stresses were concentrated on the framework and occlusal surface of the fixed partial denture, and lower stress was distributed to the alveolar bone [3].

External hexagon, internal hexagon and Morse taper are connection types of the platform of dental implants. The three types of connections present advantages, disadvantages, and different clinical indications. Since the dental implant was developed to support loads during the chewing function, some methodologies have evaluated the different connections of implants [4-11].

It has been alleged that there are inherent biomechanical differences between implants for treatment of completely edentulous arch and posterior partially edentulous segment. The partial prosthesis does not benefit from cross-arch stabilization and it is more susceptible to bending loads. Mobility between tooth and implant is different, and implants may carry a major share of load when mixed with teeth in the same quadrant. However, the frequency of implant overload in posterior partial restorations is low, and overload in this situation is almost always preventable [12]. This fact depends of the number and geometric configuration as the implants are placed. However, there was no evidence that exists advantage of the offset placement in reducing the strain around the implant [8].

Photoelasticity is a method with relative facility for construction of models and interpretation of the results, and it allows to observe the distribution of stress throughout the structure, enabling a general insight of the behavior of model. This analysis provides visual display of stress in the model with the aid of polariscope. Two types of fringes (stress) are revealed using polariscope: colored patterns (clear) which are the isochromatic fringes, representing the intensity of the stress; and the dark lines, isoclinics calls, overlapping the colored fringes related to direction of tension. The preview of the internal stress in model is the major advantage of the method based in the passage of light through of the model of geometrical configuration, and in the generation of colorful patterns that are the isochromatic fringes. These fringes are proportional to exercised stress, and the main informations required in dentistry are location and intensity of stress concentration, which can be photographed and/or measured. Conversely, in analytical methods are necessary graphics and distribution scheme of forces built from numeric data [13].

Different methodologies have evaluated the alignment of implants showing different findings. The placement of an offset implant reduces the stress, but the reduction did not compensate the increase found with off-axis loading [14]; offset placements provided no advantage for the stress decreasing over in-line placement [15]; angled system did not induce a stress concentration around the implant that was different from that of straight system [16], and offset placement is capable of reducing the strain around the implant; however, axial or nonaxial loadings have not influence until 2 mm-offset [17].

Considering the controversial results aforementioned, it would be also timely to verify the effect of the biomechanical behaviour promoted by the abutment/alignment of implants association when submitted to different directions of loading. The purpose of this study was to evaluate, by photoelastic analysis, the stress induced on partial fixed prosthesis supported by three aligned implants submitted to axial or oblique loads at first molar. The hypothesis tested was that aligned implants would promote different stresses on partial fixed prosthesis when the first molar was submitted to axial or oblique loads.

MATERIALS AND METHODS

Three rectangular models (46x30x10 mm) with three holes distant 3 mm among them were made using the NURBS (non-uniform rational b-spline) Rhinoceros 5 Program (Rhinoceros NURBS modeling for windows; Robert McNeel, Seattle, WA, USA). Afterwards, the respective analogs of the implants were fixed with cyanoacrylate glue, the square transferees connected to the analogs, and the bond between them made with dental floss and acrylic resin (Duralay; Reliance Dental, Chicago, IL. USA). The impression of the models was made with industrial silicone (Sapeca Arts and Crafts, Bauru, SP, Brazil) using a rigid PVC ring as customized tray.

After silicone polymerization at room temperature, three implants of each type (EH - external hexagon, IH - internal hexagon or MT - Morse taper) were linearly placed in each mold and connected to the square transferees for impression. The photoelastic resin (PL-2; Vishay Measurements, Raleigh, NC, USA) was manipulated according to manufacturer's instructions and placed in the silicone mold. The mold was left in a vacuum chamber with a pressure of 40 lbf/pol^2 for 24 h to remove residual air bubbles.

The fixed partial prosthesis with three elements (second premolar, and first and second molars) were conventionally made with Ni-Cr alloy (Fit Cast-SB Plus; Talladium, Curitiba, PR, Brazil). The crowns were made using 3 Series Scan (Dental Wings-DWOS; Montreal, Canada), waxed according to teeth anatomy, and casted by the lost wax method. The partial fixed prosthesis was screwed in the respective implants of the photoelastic model, and the first molar submitted to load of 100 N in axial (AL) or 45 degrees-oblique direction (OL). The stresses were observed with circular polariscope (LPM-FEMEC-UFU; Uberlandia, MG, Brazil), and the photographs were taken with digital camera (Nikon D80; Nikon, Tokyo, Japan).

The quantitative analyze was made by a graphic software (Fringes; MATLAB Plataform, LPM-FEMEC-UFU), and the qualitative analysis was visual. The following experimental groups were accomplished: EH/AL – External hexagon implants linearly placed, master screw connection, UCLA, and axial load; IH/AL- Internal hexagon implants linearly placed, master conect Ar connection, UCLA, and axial load; MT/AL- Morse taper implants linearly placed, master AR Morse connection, UCLA, and axial load; EH/OL – External hexagon implants linearly placed, master screw connection, UCLA, and oblique load; IH/OL – Internal hexagon implants linearly placed, Master Conect Ar connection, UCLA, and oblique load; and MT/OL- Master tape implants linearly placed, Master AR Morse connection, UCLA, and oblique load.

The analysis of the fringe pattern was accomplished by a color scale, considering that the isocromatic fringes are defined by the program according to the stress levels at a given point in the model. The value of the color scale was visualy adjusted by the specific color pattern by means of calibration table of the program. The specific color pattern was converged for a final value of the fringe orders (Nf) in a data grid.

For the standardization of reading of the fringe orders, in the photoelastic model were selected 12 points around each implant. The points were mapped according to obtained images in the photoelastic model. All models were analyzed using template with measures of width and length corresponding to dimensions of photoelastic model, and the selected points from the grid inserted in the Fringes program.

Statistical analysis for T (MPa) was accomplished by two-way ANOVA followed by Tukey's test at significant level of α=0.05%. The factors analysed were type of implant and direction of the applied load.

RESULTS

Qualitative analysis

Group EH/AL - Axial load applied on the first molar promoted greater stress on the implant apexes of the second premolar and first molar, and lower intensity at implant apex of the second molar (Figure 1).

Group IH/AL - Axial load applied on the first molar showed similar stress at the implant apexes of the first and second molars, and larger intensity at the implant apex of the second premolar (Figure 2).

MT/AL - Axial load applied on the first molar promoted higher stress with different concentrations among the apex regions of the three implants (Figure 3).

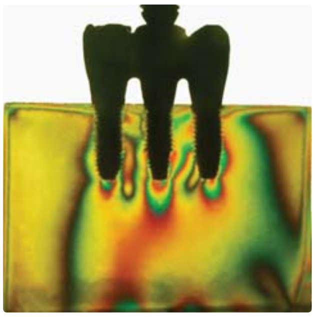

Figure 1: External hexagon/Axial load, and aligned implants.

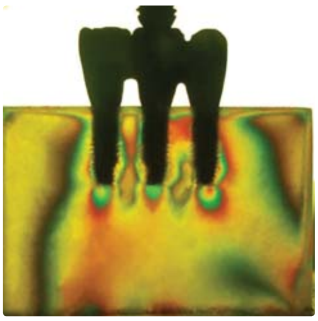

Figure 2: Internal hexagon/Axial load, and aligned implants.

Figure 3: Morse taper/Axial load, and aligned implants.

EH/OL - Oblique load applied on the first molar promoted lower stress intensity at the apex regions of the second molar and second premolar when compared to first molar (Figure 4).

IH/OL - Oblique load applied on the first molar promoted stress distribution with similar intensity at the apex regions of the three implants (Figure 5).

MT/OL - Oblique load applied on the first molar promoted greater at the second molar, and smaller at the first molar and second premolar (Figure 6).

Quantitative analysis

(Table 1) shows the means of shear stress (T - MPa) and fringe order (Nf) in the axial and oblique loads exerted at first molar in implants linearly positioned. Lower means for T were shown in IH/AL and IH/OL with statistically significant difference when compared to other associations related to the same load type. Lower Nf values were also shown for IH/AL and IH/OL groups in relation to other associations related to the same load type.

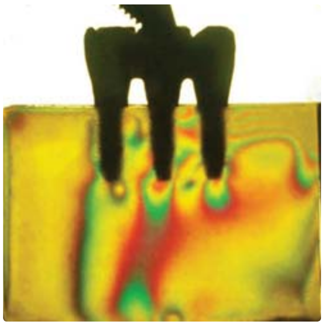

Figure 4: External hexagon/Oblique load, and aligned implants.

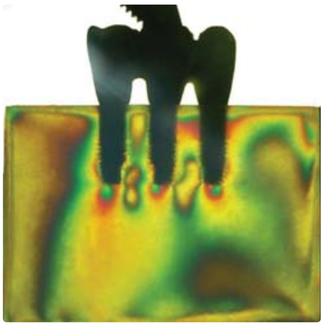

Figure 5: Internal hexagon/Oblique load, and aligned implants.

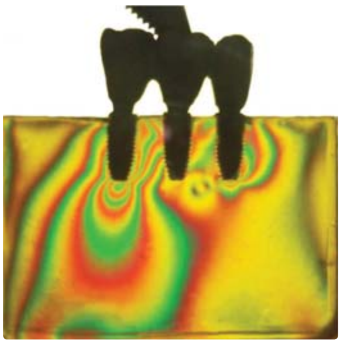

Figure 6: Morse taper/Oblique load, and aligned implants.

Table 1: Means of T (MPa) and Nf in the axial and oblique loads at the first molar in implants linearly positioned.

	Axial load			Oblique load		
	EH/AL	IH/AL	MT/AL	EH/OL	IH/OL	MT/OL
T	15.32 a	13.29 b	15.29 a	15.29 B	14.15 C	17.08 A
Nf	1.53	1.32	1.52	1.52	1.41	1.70

Means followed by different lower case letters for axial load and capital letters for oblique load differ statistically by Tukey's test (5%).

DISCUSSION

The photoelastic analysis showed different stress concentrations among the groups; therefore, the hypothesis that aligned implants would promote different stresses on partial fixed prosthesis when the first molar was submitted to axial or oblique loads was accepted.

More critically than in natural tooth, the control of the occlusal forces is determinant in the oral rehabilitation with osseointegrated implants. The effect of the force excess is shown in two distinct interfaces: Implant/abutment and implant/bone. Therefore, the implant can favorably respond to axial load whatever the type of prosthetic connection. In normal conditions, the load is distributed on the implant threads and transferred to alveolar bone without damage to prosthetic restoration [18]. However, the bending moment resulting from non-axial overloading in dental implants can cause stress concentration exceeding the physiological capacity of the cortical bone, leading to various types of failures [19].

The transference of forces from the prosthesis to implant and alveolar bone depends of several factors, as quality and quantity of the alveolar bone, implant and prosthesis material types, implant geometry, and localization, number and dimension of the connections. Other important fact is the occlusal loading location that may increase or decrease the stress concentrate levels on the framework and alveolar bone [3].

In this current study, the qualitative analysis showed less stress distribution in aligned implants only for the associations IH/AL (Figure 2) and IH/OL (Figure 5) in relation to the same load type when compared to other groups (Figures 1 and 3; 4 and 6, respectively). Similarly, lower T values with statistically significant difference, and lower Nf values were shown for the same groups (Table 1). In contrary, axial or oblique loads associated with external connection (EH/AL and EH/OL) or Morse taper (MT/AL and MT/OL) showed greater stress concentrations, higher shear stress (T) and fringe order values (Nf).

Photoelastic stress analysis showed that, when loaded off-center, the internal-implant abutment connection produces less stress when compared to external-implant abutment connection [20], and internal connection promotes better stress distribution when compared to those originated by external connection [4,5].

It has been alleged that the axial load would be preferred to improve the prosthesis/implant and implant/bone relations because the oblique load increases the stress concentration in the model [21]. From the biomechanical point of view, this condition could be more favorable for the internal hexagon implant that for external hexagon and Morse taper implants. Thus, the best stability of the abutment/implant interface with the internal connection could decrease the possibility of occurrence of mechanical micromovements during the masticatory procedure.

In agreement, some studies showed that vertical forces produce less stress than oblique forces in 3D-finite element analysis [22]; lower stress values were recorded for configuration with wider implants placed in a straight line; however, straight placement of wider implants may decrease the bending moment [19]; and internal connection system implants show more favorable stress distribution pattern than external connection system implants [11]. Conversely, 3D-anisotropic finite element analysis showed that the stress at cortical and trabecular bones around the implant did not show difference between the in-line and offset placements [15].

Photoelastic studies showed that under an off-center load, the internal-hex inferface also presented the lowest stress concentraton [23], and the type of connection system did not have direct influence on the stress distribution for axial loading [24]. Conversely, different methodologies evaluating the relation among internal hexagon, external hexagon, and Morse tape did not show diferences in the stress concentration promoted by these different configurations of implants [8,9,23].

However, an in vivo radiographic study analyzing different implant/abutment connection types under occlusal loading showed that alveolar bone changes were not significant during the healing phase and in the loading at three and six months after implant placement [25]. Interesting approaches not performed in the current study showed that cemented and mixed suprastructures submitted to compressive load displayed lower levels of stress distribution and lower intensity fringes compared to screwed prosthesis [26], and stress around the implant increased with the decrease of the implant number [27].

Axial and non-axial loadings are resulting from masticatory effort. According to bone theories, bones carrying mechanical loads adapt the strength to load applied by bone modeling/remodeling. This fact also can be applied to the alveolar bone surrounding of dental implant. The response to an increased mechanical stress below a certain threshold will be a strengthening of the bone by increasing the density or apposition of bone tissue. Conversely, fatique microdamage resulting in bone resorption may be a result of mechanical effort beyond this threshold [28].

Axial load is more favorable because the stress is homogenously distributed throughout the implant, while nonaxial load exerts high stress gradient, and implant and alveolar bone strains. As result, the stress or strain levels induced on alveolar bone can determine neoformation or resorption of the bone around the dental implant [29].

It has been alleged that the main objective for a successful dental implant is that the loads are safely transfer to interfacial alveolar bone. The biomechanics is an significant factor in several topics; however, the basic objective would be to verify the loading components exerted on implants in different clinical situations (single support or multiple supports). Significant theoretical models have been presented for determining the forces among dental implants supporting metal framework. However, more work will be needed to clarify how well these models match reality. Interfacial stress transfer and interfacial biology represent more difficult problems and are interrelated [30].

CONCLUSIONS

In this study was possible to conclude that: 1. Aligned implants promoted different effects on the stress induced when the first molar of the partial fixed prosthesis was submitted to axial or oblique loads; 2. Qualitative analysis showed lower stress distribution in aligned implants for the IH/AL and IH/OL groups; and 3. Quantitative analysis showed lower T and Nf values for the IH/AL and IH/OL groups.

REFERENCES

1. Weber HP, Kim DM, Ng MW, Hwang JW, Fiorellini JP. Peri-implant soft-tissue health surrounding cement- and screw-retained implant restorations: a multi-center, 3-year prospective study. Clin Oral Implants Res. 2006; 17: 375-379. https://goo.gl/nTX2w8
2. Weinberg LA. The biomechanics of force distribution in implant-supported prostheses. Int J Oral Maxillofac Implants. 1993; 8: 19-31. https://goo.gl/KVGD3e
3. Eskitascioglu G, Usumez A, Sevimay M, Soykan E, Unsal E. The influence of occlusal loading location on stresses transferred to implant-supported prostheses and supporting bone: a three-dimensional finite element study. J Prosthet Dent. 2004; 91: 144-150. https://goo.gl/J1hZHU
4. Tonella BP, Pellizzer EP, Ferraco R, Falcon-Antenucci RM, Carvalho PS, Goiato MC. Photoelastic analysis of cemented or screwed implant-supported prostheses with different prosthetic connections. J Oral Implantol. 2011; 37: 401-410. https://goo.gl/Dy6Atn
5. Tonella BP, Pellizzer EP, Falcon-Antenucci RM, Ferraco R, de Faria Almeida DA. Photoelastic analysis of biomechanical behavior of single and multiple fixed partial prostheses with different prosthetic connections. J Craniofac Surg. 2011; 22: 2060-2063. https://goo.gl/Yx7dSk
6. Neves FD, Veríssimo AG, Neto JPC, Prado CJ, Araújo CA. Photoelastic stress analysis of different wide implant/abutment interfaces under oblique loading. Int J Oral Maxillofac Implants. 2013; 28: e39-44. https://goo.gl/wWKNav
7. Pellizzer EP, Carli RI, Falcon-Antenucci RM, Verri FR, Goiato MC, Villa LM. Photoelastic analysis of stress distribution with different implant systems. J Oral Implantol. 2014; 40: 117-122. https://goo.gl/A3cZSU
8. Nishioka RS, de Vasconcellos LG, de Melo Nishioka LN. External hexagon and internal hexagon in straight and offset implant placement: strain gauge analysis. Implant Dent. 2009; 18: 512-520. https://goo.gl/LWVrJB
9. Nishioka RS, de Vasconcellos LG, de Melo Nishioka LN. Comparative strain gauge analysis of external and internal hexagon, Morse taper, and influence of straight and offset implant configuration. Implant Dent. 2011; 20: e24-32. https://goo.gl/eoU6Mk
10. Tang CB, Liul SY, Zhou GX, Yu JH, Zhang GD, Bao YD, et al: Nonlinear finite element analysis of three implant-abutment interface designs. Int J Oral Sci. 2012; 4: 101-108. https://goo.gl/faV3QQ
11. Takahashi JM, Dayrell AC, Consani RL, de Arruda Nobilo MA, Henriques GE, Mesquita MF. Stress evaluation of implant-abutment connections under different loading conditions: a 3D-FE study. J Oral Implantol. 2015; 41: 133-137. https://goo.gl/H5UG3Z
12. Rangert BR, Sullivan RM, Jemt TM. Load factor control for implants in the posterior partially edentulous segment. Int J Oral Maxillofac Implants. 1997; 12: 360-370. https://goo.gl/tB7mWY
13. Arat Bilhan S, Baykasoglu C, Bilhan H, Kutay O, Mugan A. Effect of attachment types and number of implants supporting mandibular overdentures on stress distribution: a computed tomography-based 3D finite element analysis. 2015; 48: 130-137. https://goo.gl/p2DzbB
14. Sütpideler M, Eckert SE, Zobitz M, An KN. Finite element analysis of effect of prosthesis height, angle of force application, and implant offset on supporting bone. Int J Oral Maxillofac Implants. 2004; 19: 819-825. https://goo.gl/VZTRKM
15. Huang HL, Lin CL, Ko CC, Chang CH, Hsu JT, Huang JS. Stress analysis of implant-supported partial prostheses in anisotropic mandibular bone: in-line versus offset placements of implants. J Oral Rehabil. 2006; 33: 501-508. https://goo.gl/KZfaVR
16. Cruz M, Wassall T, Toledo EM, da Silva Barra LP, Cruz S. Finite element stress analysis of dental prostheses supported by straight and angled implants. Int J Oral Maxillofac Implants. 2009; 24:391-403. https://goo.gl/p9pztp

17. Abreu CW, Nishioka RS, Balducci I, Consani RL. Straight and offset implant placement under axial and nonaxial loads in implant-supported prostheses: strain gauge analysis. J Prosthodont. 2012; 21: 535-539. https://goo.gl/rqW7pT

18. Rangert B, Jemt T, Jorneus L. Forces and moments on Branemark implants. Int J Oral Maxillofac Implants. 1989; 4: 241-247. https://goo.gl/G2DmZH

19. Akca K, Iplikçioglu H. Finite element stress analysis of the influence of staggered versus straight placement of dental implants. Int J Oral Maxillofac Implants. 2001; 16: 722-730. https://goo.gl/xn6t5c

20. Asvanund P, Morgano SM. Photoelastic stress analysis of external versus internal implant-abutment connections. J Prosthet Dent. 2011; 106: 266-271. https://goo.gl/D2ATsG

21. Coelho-Goiato M, Pesqueira AA, Falcon-Antenucci RM, Dos Santos DM, Haddad MF, Bannwart LC, et al. Stress distribution in implant-supported prosthesis with external and internal implant-abutment connections. Acta Odontol Scan. 2013; 71: 383-288. https://goo.gl/2XCN3x

322. Modi R, Kohli S, Rajeshwari K, Bhatia S. A three-dimension finite element analysis to evaluate the stress distribution in tooth supported 5-unit intermediate abutment prosthesis with rigid and nonrigid connector. Eur J Dent. 2015; 9: 255-261. https://goo.gl/2xo3UJ

23. Bernardes SR, Araujo CA, Neto AJF, Simamoto Jr P, Neves FD. Photoelastic analysis of stress patterns from different implant-abutment interfaces. Int J Oral Maxillofac Implants. 2009; 24: 781-789. https://goo.gl/6TsZyH

24. Goiato MC, Shibayama R, Filho HG, Medeiros RA, Pesqueira AA, Dos Santos DM, et al. Stress distribution in implant-supported prostheses using different connection systems and cantilever lengths: digital photoelasticity. J Med Eng Technol. 2016; 40: 35-42. https://goo.gl/htZpoG

25. Lin MI, Shen YW, Huang HL, Hsu JT, Fuh LJ. A restropective study of implant-abutment connections on crestal bone level. J Dent Res. 2013; 92: 202S-207S. https://goo.gl/DR4Avr

26. Pimentel AC, Manzi MR, Polo CL, Sendyk CL, da Graca Naclecio-Homem M, Sendyk WR. Photoelastic analysis on different retention methods of implant-supported prosthesis. J Oral Implantol. 2015; 41: 258-263. https://goo.gl/rXJcJM

27. Lee JI, Lee Y, Kim YL, Cho HW. Effect of implant number and distribution on load transfer in implant-supported partial fixed dental prostheses for the anterior maxilla: A photoelastic stress analysis study. J Prosthet Dent 2016; 115: 161-169. https://goo.gl/CkZokR

28. Isidor F. Influence of forces on peri-implant bone. Clin Oral Implants Res. 2006; 17: 8-18. https://goo.gl/eiZzpE

29. Sahin S, Cehreli MC, Yalin E: The influence of functional forces on the biomechanics of implant-supported prostheses. A review. J Dent 2002; 30: 271-282. https://goo.gl/19X24X

30. Brunski JB. Biomechanical factors affecting the bone-dental implant interface. Clin Mater. 1992; 10: 153-201. https://goo.gl/eWdfqs