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EFFECT OF DIFFERENT RESTORATIVE CROWNS ON FRACTURE RESISTANCE AND STRESS DISTRIBUTION IN SINGLE IMPLANTS; AN IN-VITRO STUDY

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ABSTRACT

Statement of the problem. Implant failure due to poor biomechanical behavior is a common problem in dentistry. Occlusal overloading is considered the primary cause of peri-implantitis, implant and\or prosthesis fracture, and screw loosening or fracture.

Purpose. The purpose of this study was to investigate the effect of different restorative crowns on the fracture resistance and stress distribution in single implants.

Materials and Methods. One implant was anchored in a measurement model based on a real-life patient situation simulating (D3) bone density. Strain gauges (SGs) were fixed mesially, distally, lingual and buccally adjacent to the implant. A total of 20 crowns were produced using a CAD\CAM machine and divided into two equal groups according to the material type; Zirconia and (PEEK) (n=10). The magnitude of strain was recorded in microstrains (με). Each specimen was loaded to fracture in a universal testing machine with a crosshead speed of 0.5 mm/min. Data were analyzed with 2-way univariate ANOVA and Tukey HSD test (α=.05).

Results. The mean strain values for the two groups at the different (SG) sites ranged from (26.0 to 1033.6 μm/m). The 2-way univariate ANOVA indicated statistically significant differences (P <0.001) between the zirconia and the (PEEK) crowns .In addition, Mean (SD) failure loads were 2070.5(100.24) N for zirconia crowns, 950.75(34.61) N for (PEEK) crowns. The 2-way univariate ANOVA showed a statistically significant difference for the fracture resistance between the zirconia and (PEEK) crowns (P< 0.001).

Conclusions: Superstructure materials appear to have an influence on strain development in single implant restorations.

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INTRODUCTION

Dental implants have been used successfully for the rehabilitation of partially and completely edentulous patients since the early 1970s; however, failures are still unavoidable and several complications may arise that jeopardize the prognosis of the restorations. [1, 2]

Occlusal overload is considered the primary factor for peri-implantitis and may cause bending moments and high stress gradients that induce bone resorption around the implant collar resulting in implant and\or implant-supported prostheses failure.[3]

The manner in which stresses are transferred from the implants to the surrounding bone depends on the bone-implant interface, the length and diameter of the implants, the shape of the implant surface, the prosthesis type, the quantity and quality of the surrounding bone and the magnitude and direction of stresses and strains around implants.[4, 5]

Selection of implant-supported restorations is of a prime concern as destructive forces can be transmitted to the bone-implant interface resulting in marginal bone loss and catastrophic failures. In addition, the increased patients' demand for naturally-looking esthetic materials with superior mechanical properties, has led to the development of new materials. [6]

Coupled with the CAD\CAM technology, monolithic zirconia restorations without veneering ceramic have been used in patients with limited interocclusal space because of its ability to withstand high loads with only 0.5 mm occlusal thickness.[7] However, despite their high compressive strength, they are brittle materials with low tensile strength; in addition, temperature degradation (LTD) in the presence of moisture and at low temperatures (150-400°C) is considered the main drawback of these restorations due to the formation of microcracks and strength degradation.[8, 9]

Recently, Polyetheretherketone ((PEEK)) has been introduced as an alternative to metal-ceramic and full ceramic restorations in implant-supported fixed partial dentures (FPDs). (PEEK) is a synthetic, tooth colored polymeric material that has been used as a biomaterial in orthopedics for many years. The major beneficial property is its lower Young's (elastic) modulus (3-4 GPa) being close to human bone; thus, absorb energy from the masticatory cycle.[10]

It has been suggested that stress-absorbing superstructures supported by osseointegrated implants are a crucial factor determining long term implant stability and success, as they can reduce loading on the implant due to the lack of viscoelasticity at the bone-implant interface. [11]

Several techniques have been employed to evaluate the stresses on implants supported fixed prostheses, such as finite elements stress analysis, [12, 13] photoelastic stress analysis, [14, 15] mathematical calculations, [16] and strain gauge analysis.[11, 17-24]

Strain gauge analysis is a technique for measuring complex strain fields around a fixture, which involves the use of electrical resistance or strain gauges. Strain gauges are based on the principle that certain materials undergo changes in their electrical resistivity when subjected to a force. Materials with different resistivities can be measured accurately at the site where the strain gauge is bonded, using a Wheatstone's bridge circuit. [14, 21]

The purpose of this study was to evaluate the effect of different restorative crowns on the fracture resistance and stress distribution in single implants. Therefore, the hypothesis of this study was that different superstructure materials (PEEK) & zirconia has an effect on the stress distribution and fracture resistance of single implants.

MATERIALS AND METHODS

A total number of twenty full anatomical crowns were designed and constructed using CAD\CAM technology. The samples were divided into two groups of ten samples for each restorative material.

Models Fabrication

As listed in Table I, two different types of superstructures were used. Two representative models (System Three Resins; W. Valley Hwy N, USA) were fabricated to mimic bone density (D3). One model for each group simulating missing posterior first molar.[25] One Implant 13 mm length, 4.2 mm diameter, 3.5 mm platform (Reactive implant; Implant direct LLC, CA, USA, Lot # 69893) was inserted in place of lower first molar to create a bounded edentulous situation for each simulating model which was either restored by (PEEK) or zirconia crowns. Two internal titanium hex abutments 3.5 mm in diameter, 6 mm in length and 0.5 mm chamfer finishing line (Reactive implant; Implant direct LLC, CA, USA, Lot # 58376) were fixed on each implant.

Construction of the full anatomical crowns

Scanning of each model was done using a scanner (Cerec Omnicam; Sirona Dental Systems, LLC, Charlotte, NC, USA). After scanning the geometrical data of the model, a virtual framework was designed by the CAD software (Inlab software 15.0) with a standardized protocol. Biogeneric concept was used within the software to standardize anatomical configurations of the proposed virtual crowns. The settings were: a uniform wall thickness of (0.5 mm), a virtual cement layer of (60 μm) starting 1mm above the margin, after designing the crowns, checking is done for any error.[26]

Each incoris TZI medi block was then dry milled in a 5-axis milling machine (Cerec in lab MCXL, Sirona Dental Systems, LLC, Charlotte, NC, USA) with an oversize of approximately 20-25% to compensate the sintering shrinkage. Sintering of full anatomical zirconia crowns (n=10) was done in a high-temperature furnace (Sirona inFire HTC sintering furnace; Sirona Dental Systems, LLC, Charlotte, NC, USA) following the manufacturer`s instructions.

The Brecam bio Hpp blank was dry milled with the same parameters of the previously constructed crowns to fabricate (PEEK) crowns (n=10).

Temporary cement (RelyX®; 3M ESPE, Seefeld, Germany, Lot # 632799) was used to cement the crowns on their respective abutments.[27] The abutments were carefully cleaned with gauze moistened with alcohol during changing the crowns.

Strain gauges analysis

Preparation of the four different sites (Buccal , lingual , Mesial & Distal) for strain gauge bonding was performed by abrading the epoxy model with 400-grit silicon carbide abrasive paper to produce flat surfaces,[28] and then wiped clean with acetone.

The four strain gauges (CC-33A; Kyowa, Tokyo, Japan) were positioned parallel to their respective long axis and bonded to the surface of the epoxy resin model using strain gauge adhesive (cyanoacrylate resin) (Fig.1). Strain gauges were

TABLE (I) list of used materials, composition manufacturers and specifications.

Material	Composition	Manufacturer	Lot #
inCoris TZI medi block	$ZrO_2 \geq 99\%, Y_2O_3 > 4.5, HfO_2 \leq 5\%, AL_2O_3 \leq 0.04\%$	Sirona, Charlotte,NC, USA	2014040263
Bre CAM Bio HPP blank	Polyether ether ketone	Bredent,Senden,Germany	450449

left for 24 hours to ensure complete setting. All gauges were arranged in series to form a Wheatstone bridge. The lead wire from each strain gauge was connected to a multichannel strain-meter (Strain-Meter; PCD-300A, Kyowa Electronic Instruments Co.,Ltd, Tokyo, Japan) to form one leg of the bridge and to record dynamic resin model microstrains transmitted to each strain gauge. A computer (Lenovo, Intel® Pentium® D; Beijing, China) was connected with the strain-meter to record the output signal of the model surface. Data acquisition system software (PCD-3A) was used to record the data.

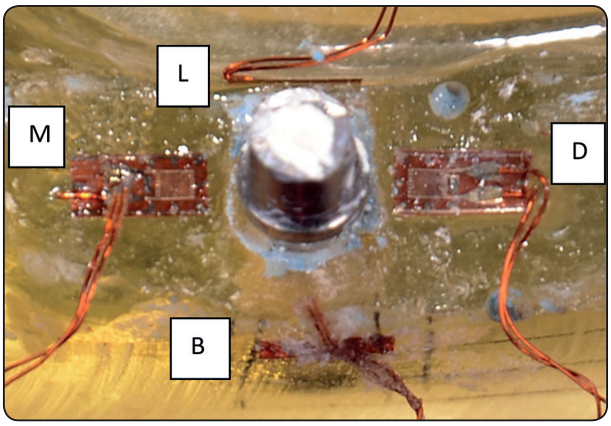

Fig. (1) Experimental resin model and strain gauge locations.

A universal testing machine (Lloyd Instruments, West Sussex, UK) was used to apply a vertical static load with the advantage of applying the load every time in the same magnitude and direction. The machine was running at a cross head speed of 0.5 mm/min. A cylindrical rod with round tip 6 mm in diameter was placed as a load applicator in the fossa of all crowns ensuring that the round tip touches all surfaces. [29] A (1-mm) thick aluminum foil was applied below the load applicator to ensure stress distribution (Fig. 2).

All strain gauges were set to (zero) at the beginning of the experimental procedure, a defined force of 200 N was applied to the crown by the universal testing machine over 30 seconds duration and maintained at this load for another 30 seconds. Then the force was removed and residual strains were released for an additional 2 minutes period. Once the load was completely applied, readings of the strains were taken in microstrain unit (με) from the multi-channel strain-meter. Each loading condition was repeated five times to ensure the reproducibility of the results.

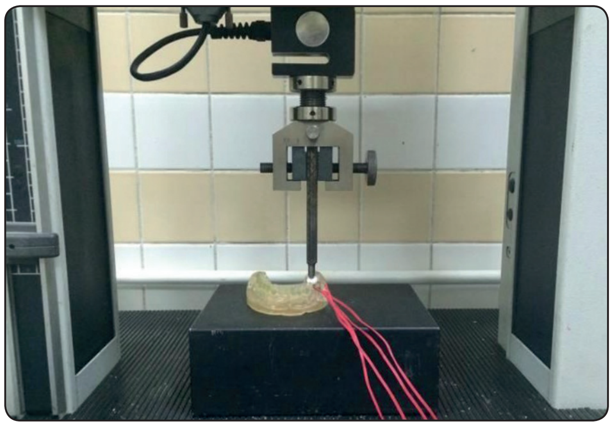

Fig. (2) Application of load in the central fossa of the molar abutment.

Load to fracture test

After strain analysis test, all crowns were compressively loaded until fracture at a crosshead speed of 0.5 mm/ min with the same load applicator (6-mm diameter) placed on the occlusal surface of the crowns. To prevent primary cracks at the point of loading, 0.5-mm thick tin foil A 1-mm thick aluminum foil was placed between the crowns and the opposing load applicator so that stress distribution on the crowns could be achieved. The compressive load required to cause fracture was recorded for each crown in Newtons. Descriptive statistics using the arithmetic mean and standard deviation (SD) of the five readings were recorded under each loading to fracture condition, calculated and tabulated.

Statistical analysis

Statistical analysis was performed with IBM® SPSS® (Version 24.0, Inc., Chicago, IL, USA). Data explored for normality using Kolmogorov Smirnov test. One Way ANOVA used to compare between tested superstructure materials. Dependent t-test used to compare between tested superstructure within each surface and for total Strain (με).

One-way ANOVA used to compare between interactions of variables followed by Tukey post hoc test for pairwise comparison for mean Fracture resistance (N). All statistical testing was performed with ($P < 0.05$) as the level of significance.

RESULTS

The mean values and standard deviation (SD) of microstrain (με) of all groups were shown in (Table II). All sites showed significant differences ($P<0.001$) between the tested implant superstructures. In relation to the overall strains, there were significant differences between both superstructures (zirconia and (PEEK)) (Fig.3).

The mean and standard deviation (SD) of Fracture resistance (N) values were 2075.50(100.24) N for zirconia crowns and 950.75(34.61) N for (PEEK) crowns. Tukey post hoc test showed statistically significant difference ($P<0.001$) between the two groups (Fig.4).

TABLE (II) Mean and standard deviation (SD) for Strain (μm/m) for tested superstructure material.

		(PEEK)		Zirconia		P-value
	Site	Mean	SD	Mean	SD	
Implant supported superstructure	**Distal**	495.00[b]	19.69	741.67[a]	33.63	≤0.001*
	Buccal	108.33[b]	20.37	235.00[a]	29.90	≤0.001*
	Mesial	205.56[b]	15.84	327.00[a]	20.49	≤0.001*
	Lingual	45.00[b]	8.66	91.67[a]	18.03	≤0.001*

Significant at P ≤ 0.05, Different letters are statistically significant different.

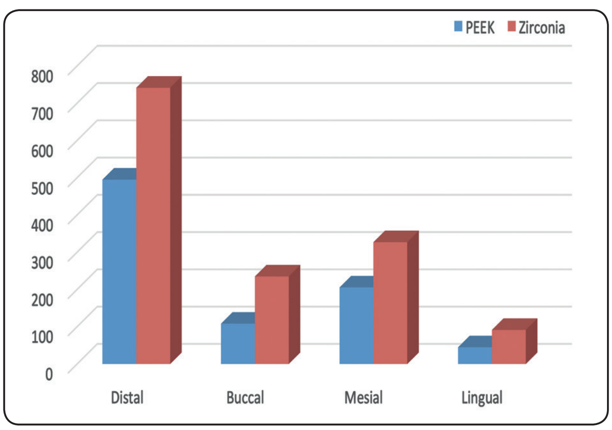

Fig. (3) Bar chart showing the mean strain induced (με) in different sites for different tested superstructure material over the molar abutment.

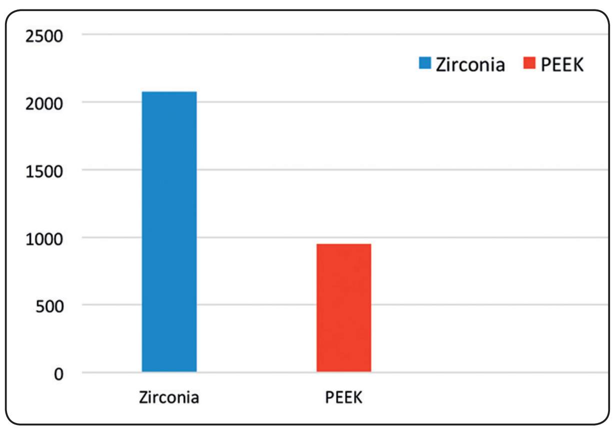

Fig. (4) Bar chart showing the mean Fracture resistance (N) for different superstructure materials.

DISCUSSION

The hypothesis of this study that different abutment superstructures play an important role in stress distribution and fracture resistance of implant supported restorations was accepted.

The highest successful rates of osseointegrated implants have been observed in areas with bone tissue type D1 and D2 according to Zarb's classification [30]; however, unsatisfactory results have been seen in predominantly bone marrow. [4] In this study, to better simulate clinical conditions, object with the same modulus of elasticity of bone marrow (epoxy resin=5GPa; bone marrow=4.25GPa) has been selected. The epoxy resin model was assumed to be linearly elastic and isotropic (the same properties in different directions); in reality the bone is anisotropic and it contains voids. The authors in previous studies used these models to eliminate the effects of variations in bone quality [22, 31, 32]; however, other studies utilized bone blocks. [33, 34]

The cervical region of the implant is the site where the highest stresses occur despite of the bone type and the implant design. [35] In this study, the strain gauges were bonded tangentially to the implant platform on the resin block. Furthermore, the flat surface of the resin block facilitates the positioning and bonding of the strain gauges when compared with other studies, which are bonded to the implants [13] , to the metallic framework of the prosthesis,[19,35] and to the abutment.[36] This positioning of the strain gauges method has been used in previous studies. [17, 19, 20-22, 37]

In this study, implant with internal hexagon connection was used for its greater mechanical friction, stability and form lock than the external hexagon joint. This study agrees with Freitas et al. study [38] that demonstrated that higher levels of stresses were observed in the external hex rather than internal hex implant abutment connection.

In the present study, zirconia and (PEEK) implant superstructures were used to satisfy the patients' esthetic demands. Zirconia superstructures were used in many studies to overcome the drawbacks of the porcelain fused to metal superstructures for its high esthetic outcome and high fracture resistance. (PEEK) (poly-ether-ether-ketone) is a high-performance thermoplastic polymer with excellent biocompatibility and superior mechanical properties that can tolerate plastic deformation, in both uniaxial tension and compression. [39]

The results of this study showed that the strains developed in the buccal surfaces were found to be the higher than the lingual strain gauges among the different tested superstructure (Table II) and (Fig.3). This could be explained by Alkan et al. [40] who found that stress concentration developed more at the buccal strain gauges than the strains developed at the other surfaces. The higher strains were attributed to slight anatomic lingual inclination of the mandibular teeth which was duplicated in the simulated epoxy resin model resulting in higher tensile and compressive stresses found on the buccal surface.

Contradictory results were documented by Papavasilliou et al. [41] who stated that due to the vertical implant placement, according to the concept of optimal axial loading and at right angles to the occlusal plane which may be at the expense of the buccal bone volume. The decrease of cortical bone stimulant thickness might have increased the strain levels lingually. [42]

The results of this study showed that the strains developed around all implant superstructures (PEEK) and zirconia) were found to be higher at the distal and mesial strain gauges than the other surfaces (Table II). This was supposed to be due to that the mesial and distal surfaces around the implants were nearly perpendicular to the plane of bending; thus, deformation at these surfaces could be attributed to both the axial forces and the bending movements generated by loading the superstructure. [43]

Contradictory results were documented by many studies [44, 45] who found that the strains were higher at lingual surfaces than those at the mesial and distal surfaces of the implants. This is due to the natural lingual inclination of the lower teeth.

In this study, two different superstructure materials were used over the dental implant. The strains developed around the zirconia crowns were higher than (PEEK) crowns (TableII). The results of this study are in agreement with those of previous invitro studies, [42, 46] who found that the strains developed around (PEEK) superstructure were lower than those developed around zirconia superstructure due to the difference in the elastic modulus of each material. Supporting to the results of this study, Mascarenhas et al.[47] postulated that higher elastic modulus of superstructure material allowed for a more uniform stress distribution within the framework; thus, providing a more efficient and reliable load transfer to the implants. The large difference in the elastic moduli between the components of superstructure (zirconia=210 GPa, (PEEK) =5Gpa) [29] might have changed the overall elastic behavior of these superstructure under occlusal loading. [48]

The fracture strength of monolithic zirconia crowns was significantly higher than the peak crowns ($P \leq 0.05$). Mean values of the fracture resistance for the zirconia and (PEEK) crowns were (2075.50, 950 N, respectively) (Fig.4).Foong et al. [49] documented a higher fracture resistance of zirconia superstructure (1108 N), while Kurun et al. [50] obtained lower values of the fracture strength of the zirconia crowns with PFM superstructure (457 N).

Mericske et al. [51] reported maximum occlusal force of 206.1±87.6 N for the first premolars, 209.8±88.2N for molars, and 293.2±98.3 N for second premolars in patients wearing implant-supported partial fixed prostheses. Strain gauge studies in the implant field generally use low loads varying from 20 to 300 N.[13,17] Some authors in previous studies utilized custom load application devices,[13,15]while others used universal testing machines.[17,36] However, the force used in the universal testing machine is considered too great for testing small values employed in dentistry, since it is used mainly in the engineering field that requires high force.[24] In this study, static axial loads of (200 N) were slightly higher than those reported by Mericske et al. [51] who found values close to those found in this present study.

There were limitations of this study. All specimens were anatomically prepared to simulate the human condition; however, monolithic (PEEK) crowns cannot be recommended for clinical application. This study did not simulate human mastication or the oral environment; therefore, clinical investigations with long follow up are needed to assess the clinical performance of these restorations.

CONCLUSIONS

Within the limitations of this in-vitro study, the following conclusions were drawn:

1. Different superstructure materials affect the stress pattern induced around dental implants.
2. (PEEK) crowns had a favorable effect on the stress distribution when compared to Zirconia crowns.
3. Fracture resistance of the zirconia crowns is higher than (PEEK) crowns; however, both crowns exceed the fracture resistance required to withstand masticatory forces assumed for posterior region.

REFERENCES

1. Sahin S, Cehreli MC, Yalcin E. The influence of functional forces on the biomechanics of implant-supported prostheses-a review. J Dent 2002; 30:271-282.
2. Levin L. Dealing with dental implant failures. J Appl Oral Sci 2008; 16:171-5.

3. Naert I., Duyck J., Vandamme K. Occlusal overload and bone/implant loss. Clin Oral Implants Res 2012; 23:95-107.

4. Sousa TC, Lelis V, Santos VM, Nishioka GN, Vasconcellos LG, Nishioka RS. Strain Gauge analysis of non-axial loads in three-element implant-supported prostheses. Braz Dent Sci 2013; 16:24-30.

5. Sadid-Zadeh R, Liu PR, Aponte-Wesson R, O'Neal SJ. Maxillary cement retained implant supported monolithic zirconia prosthesis in a full mouth rehabilitation: a clinical report. J Adv Prosthodont 2013; 5:209-217.

6. Parmigiani-Izquierdo JM, Cabaña-Muñoz ME, Merino JJ, Sánchez-Pérez A. Zirconia implants and peek restorations for the replacement of upper molars. Int J Implant Dent 2017; 3:3-5.

7. Özkurt-Kayahan Z. Monolithic zirconia: A review of the literature. Biomedical Research 2016; 27: 1427-1436.

8. Guess PC, Schultheis S, Bonfante EA, Coelho PG, Ferencz JL, Silva NR. All-ceramic systems: laboratory and clinical performance. Dent Clin North Am 2011; 55: 333-352.

9. Pereira G, Amaral M, Cesar PF, Bottino MC, Kleverlaan CJ, Valandro LF. Effect of low-temperature aging on the mechanical behavior of ground Y-TZP. J Mech Behav Biomed Mater 2015; 45: 183-192.

10. Yuan, B.; Cheng, Q.; Zhao, R.; Zhu, X.; Yang, X.; Yang, X.; Zhang, K.; Song, Y.; Zhang, X. Comparison of osteointegration property between PEKK and PEEK: Effects of surface structure and chemistry. Biomaterials 2018; 170, 116-126.

11. Carvalho AO, Bruzi G, Giannini M MP. Fatigue resistance of CAD/CAM complete crowns with a simplified cementation process. J Prosthet Dent 2014; 111:310-317.

12. Barbier L, Vander Sloten J, Krzesinski G, Schepers E, Van der Perre G. Finite element analysis of non-axial versus axial loading of oral implants in the mandible of the dog. J Oral Rehabil 1998; 25:847-858.

13. Akça K, Cehreli MC, Iplikçioglu H. A comparison of three-dimensional finite element stress analysis with in vitro strain gauge measurements on dental implants. Int J Prosthodont 2002; 15:115-121.

14. Clelland NL, Gilat A, McGlumphy EA, Brantley WA. A photoelastic and strain gauge analysis of angled abutments for an implant system. In J Oral Maxillofac Implants 1993; 8:541-548.

15. Ueda C, Markarian RA, Sendyk CL, Laganá DC. Photoelastic analysis of stress distribution on parallel and angled implants after installation of fixed prostheses. Braz Oral Res 2004; 18:45-52.

16. Weinberg LA, Kruger B. A comparison of implant/prosthesis loading with four clinical variables. Int J Prosthodont 1995; 8:421-433.

17. Abreu CW, Vasconcellos LGO, Balducci I, Nishioka RS. A comparative study of micro strain around three-morse taper implants with machined and plastic copings under axial loading. Braz J Oral Sci 2010; 9:11-15.

18. Castilho AA, Kojima AN, Pereira SM, Vasconcellos DK, Itinoche MK, Faria R, et al.. In vitro evaluation of the precision of working casts for implant-supported restoration with multiple abutments. J Appl Oral Sci 2007; 15:241-246.

19. Heckmann SM, Karl M, Wichmann MG, Winter W, Graef F, Taylor TD. Loading of bone surrounding implants through three-unit fixed partial denture fixation: a finite-element analysis based on in vitro and in vivo strain measurements. Clin Oral Implants Res 2006; 17:345-350.

20. Nishioka RS, Nishioka LN, Abreu CW, Vasconcellos LG, Balducci I. Machined and plastic copings in three-element prostheses with different types of implant-abutment joints: a strain gauge comparative analysis. J Appl Oral Sci 2010; 18:225-230.

21. Nishioka RS, Vasconcellos LG, Melo Nishioka LN. External hexagon and internal hexagon in straight and offset implant placement: strain gauge analysis. Implant Dent 2009; 18:512-520.

22. Nishioka RS, Vasconcellos LG, Melo Nishioka GN. Comparative strain gauge analysis of external and internal hexagon, Morse taper, and influence of straight and offset implant configuration. Implant Dent 2011; 20:e24-e32.

23. Hekimoglu C, Anil N, Cehreli MC. Analysis of strain around endosseous dental implants opposing natural teeth or implants. J Prosthet Dent 2004; 92:441-446.

24. Nishioka R.S., de Vasconcellos L.G., Joias R.P., & Rode Sde M. Load-application devices: A comparative strain gauge analysis. Braz Dent J 2015; 26: 258-262.

25. Jung RE, Zembic A, Pjetursson BE. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res 2012; 23:2-21.

26. Greenstein G, Cavallaro J. Failed dental implants: diagnosis, removal and survival of reimplantations. J Am Dent Assoc 2014; 145:835-42.

27. Papaspyridakos P et al. Implant success rates for single crowns and fixed partial dentures in general dental practices may be lower than those achieved in well-controlled university or specialty settings. J Evid Based Dent Pract 2015; 15:30-2.

28. Tuna T,Yorgidis M and Strub J.R: Prognosis of implants and fixed restorations after lateral sinus elevation: a literature review. J. Oral Rehabil 2012; 39:226-38.

29. Carl Drago. Implant Restorations: A Step-by-Step Guide, Wiley-Blackwell, 3rd Edition. 2014: 58-66.

30. Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants: The Toronto study. Part III: Problems and complications encountered. J Prosthet Dent 1990; 64:185-94.

31. Watanabe F, ,Uno I, Hata Y, Neuendorff G, Kirsch A. Analysis of stress distribution in a screw-retained implant prosthesis. Int J Oral Maxillofac Implants 2000; 15:209-18.

32. Heckmann SM, Karl M, Wichmann MG, Winter W, Graef F, Taylor TD. Cement fixation and screw retention: parameters of passive fit. An in vitro study of three-unit implant-supported fixed partial dentures. Clin Oral Implants Res 2004; 15:466-73.

33. Çehreli MC, Akkocaoglu M, Comert A, Tekdemir I, Akca K. Human ex vivo bone tissue strains around natural teeth vs. immediate oral implants. Clin Oral Implants Res 2005; 16:540-8.

34. Akça K, Kokat AM, Sahin S, Iplikçioglu H, Çehreli MC. Effects of prosthesis design and impression techniques on human cortical bone strain around oral implants under load. Med Eng Phys 2009; 31:758-63.

35. Karl M, Wichmann MG, Winter W, Graef F, Taylor TD, Heckmann SM. Influence of fixation mode and superstructure span upon strain development of implant fixed partial dentures. J Prosthodont 2008; 17:3-8.

36. Seong WJ, Korioth TW, Hodges JS. Experimentally induced abutment strains in three types of single-molar implant restorations. J Prosthet Dent 2000; 84:318-326.

37. Shimura Y, Sato Y, Kitagawa N, Omori M. Biomechanical effects of offset placement of dental implants in the edentulous posterior mandible. Int J Implant Dent 2016; 2:17.

38. Freitas-Junior AC, Rocha EP, Bonfante EA, Almeida EO, Anchieta RB, Martini AP, et al. Biomechanical evaluation of internal and external hexagon platform switched implant-abutment connections: an in vitro laboratory and three dimensional finite element analysis. Dent Mater 2012; 28:e218–28.

39. Stawarczyk B, Eichberger M, Uhrenbacher J, Wimmer T, Edelhoff D, Schmidlin PR. Three-unit reinforced polyetheretherketone composite FDPs: Influence of fabrication method on load-bearing capacity and failure types. Dent Mater J 2015; 34: 7-12.

40. Alkan I, Sertgöz A, Ekici B. Influence of occlusal forces on stress distribution in preloaded dental implant screws. J Prosthet Dent 2004; 91:319-25.

41. Papavasilliou G, Kamposiora P, Bayne SC and Felton DA: Three dimensional finite element analysis of stress distribution around single tooth implant as a function of bony support, prosthesis type, and loading during function. J Prosthet Dent 1996; 76: 633-40.

42. Duaibis R, Kusnoto B, Natarajan R, Zhao L, Evans C. Factors affecting stresses in cortical bone around mini screw implants A three-dimensional finite element study. Angle Orthod. 2012; 82:875-880.

43. Karl M1, Holst S. Strain development of screw-retained implant-supported fixed restorations: procera implant bridge versus conventionally cast restorations. Int J Prosthodont 2012; 25:166-9.

44. Andreas Dominik Schwitalla, Tobias Spintig, Ilona Kallage, Wolf-Dieter Müller. Pressure behavior of different PEEK materials for dental implants. Journal of the Mechanical Behavior of Biomedical Materials 2016; 54: 295-304.

45. Atefi E, Mallakzadeh M. Investigating the effect of bone mass density and bone implant interface on mandible stress and strain using nonlinear finite elements method[C]// Biomedical Engineering (icbme), 2010 17th Iranian Conference of. IEEE, 2010; 1-4.

46. Kokubyo Gakkai Zasshi. An analysis of stress around abutment teeth and periodontium in three-unit fixed partial dentures-photoelastic analysis with simulated periodontal ligament. 2011; 78:19-27.

47. Faye Mascarenhas, Burak Yilmaz, Edwin McGlumphy Nancy Clelland, Jeremy Seidt. Load to failure of different zirconia implant abutments with titanium components. J Prosth Dent 2017; 117:749-754.

48. Arturo N. Natali. Dental Biomechanics, Elsevier, first edition, 2003:6-11.

49. Foong, Jamie K.W. et al. Fracture resistance of titanium and zirconia abutments: an in vitro study. J Prosthet Dent 2013; 109:304-312.

50. Kurun S, Att W1, Gerds T, Strub JR. Fracture resistance of single-tooth implant-supported all-ceramic restorations after exposure to the artificial mouth. J Oral Rehabil 2006; 33:380-6.

51. Mericske-Stern R, Assal P, Mericske E, Bürgin W. Occlusal force and oral tactile sensibility measured in partially edentulous patients with ITI implants. Int J Oral Maxillofac Implants 1995; 10:345-353.