EGYPTIAN
DENTAL JOURNAL

Vol. 63, 3823:3832, October, 2017

I.S.S.N 0070-9484

Fixed Prosthodontics, Dental materials, Conservative Dentistry and Endodontics

www.eda-egypt.org • Codex : 161/1710

EFFECT OF TWO DIFFERENT RESTORATIVE MATERIALS ON STRESS DISTRIBUTION ON ALL-ON-FOUR IMPLANT RETAINED RESTORATIONS

Ahmed Ezzat Sabet*

ABSTRACT

Purpose: The purpose of this in vitro study was to evaluate the effect of restorative material either zirconia or BioHPP on stress distribution affecting periimplant supporting structures.

Materials and methods: Four implants were installed using a surveyor in a maxillary model. Scan bodies were used to scan implant fixture position using identica hybrid desktop scanner then Exocad software was used to design a cutback implant retained restoration. VHF 5 axis milling machine was used for manufacturing of zirconia & bioHPP restoration from the same STL design, veneering was then performed by feldspathic porcelain & composite respectively. Strain gauge was installed 1mm distal to implant fixture. Universal testing machine was used to apply both axial & off axial loads 100 N & microstrains were recorded to test amount of developed strain around implant.

Results: The results of independent t test showed that there was no statistically significant effect between bioHPP and Zirconia groups under axial loading ($p= 0.064$) and off axial loading ($p=0.11$)

Conclusions: Based on the present in vitro results, the change in restoration material did not affect the stress distribution in implants and peripheral bone under axial & off axial loads.

INTRODUCTION

Edentulism is the terminal outcome of a multifactorial process including biological processes such as caries, periodontal diseases, pulpal pathology, trauma, oral cancer as well as non-biologic factors related to dental procedures. It is conservatively assumed that 10 % of the world's population of 6 billion is between partially or totally edentulous. The choice between a fixed prosthesis and an overdenture when treating the edentulous mandible with implants shows wide variation both within and between countries. (1)

A wide variety of treatment modalities exist for the edentulous patient. Implants were originally developed to provide an innovative and more reliable solution for patients struggling to adapt to complete

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* Lecturer, Fixed Prosthodontics Department, Ain Shams University

dentures. (2) The critical number, distribution, and bony support of endosseous implants for carrying fixed bridges with good long term prognosis have not been as thoroughly investigated as have the number of teeth and the amount and distribution of periodontal support needed for tooth anchored bridges. The obtained surface of bone-to implant contact is dependent on the area of the surface of the implant and the density of the surrounding bone. (3)

The original design for the edentulous patient was the fixed implant-supported prostheses. Many patients prefer this design as it provides them with a "natural feel" which they find comparable to their own teeth regarding both aesthetics and function. In addition, fixed implant prostheses require less maintenance, as there are no attachments to change or adjust. However, this type of treatment may be beyond the financial and anatomical scope of many edentulous patients. In addition, attempting to reduce the number of implants supporting a full arch fixed prosthesis may result in biomechanical disadvantages as increased stresses on the implants. (4)

In order to support mandibular fixed full arch implant prosthesis, four to six implants are placed in the foramina area, fixed full-arch implant supported prosthesis is indicated in the presence of enough bone and interarch space. However, when there is loss of soft and hard tissue to support the facial tissue by the buccal denture flange, fixed prosthesis is contraindicated. (5)

In case of splinted implant prosthesis, it is possible that the restoration itself may transmit strain to the bone-implant interface. Ideally the restoration would fit passively without any undue pressure on the supporting implants, thus minimizing strain and the concomitant biological response. (6)

A further advantage of these implant –supported fixed bridges is that they are less expensive due to relative simplicity of the manufacturing process if CAD/CAM technology is applied. (7)

Recent evolutions in dental materials, Innovative Computer aided design/computer-aided manufacturing (CAD/CAM) technology, and 3-dimensional (3-D) imaging coupled with interactive treatment planning concepts have provided clinicians with new, predictable treatment options for their patients allowing for prosthodontically-driven implant placement and optimum substructure design for optimal aesthetics and biomechanics. (8)

A CAD/CAM screw-retained implant fixed prosthesis negates many of the complications of the prosthetic alternatives. The fact that it is produced through a CAD/CAM protocol and not the lost-wax casting technique helps to resolve any issues with casting distortion.((8)1)

In the past 15 years, zirconia has gained worldwide acceptance due to the CAD/CAM technique and has forced significant quantity of metallic alloys off the market (9)

Several systems are available, some of which involve the technicians to build the cores using the wax up technique, and then this wax up is scanned by computer either by contact scanning or laser scanning that have similar precision (10), and finally the milling of ready made zirconium blocks occur, while other systems involve scanning of the impressions and the CAD takes place where the computer design the framework allowing adjustments by the technicians, then the CAM takes place where they are milled from the blocks. (11) Nowadays, some systems mill the whole crowns and bridges with zirconia rather than veneering them with porcelain and certain attains are used to modify their colors to match teeth exactly. (12-14)

Due to the increasing interest in esthetics and concerns about toxic and hypersensitivity reactions to certain alloys and metals, both patients and dentists have been in a continuous search for metal free tooth-colored restorations. Therefore, the development of new innovative high strength dental ceramics, which is less brittle, less limited in their tensile strength, and less subject to time dependent stress failure, has dominated in the later part of 20th century. These features are greatly attractive in prosthetic dentistry, where strength and esthetics demands are paramount. ((15)

More recently, zirconia has been one of the major advancements in the field of implant prosthodontics and has been the result of the implication of engineering principles in the form of computer aided design and computer aided manufacturing (CAD/CAM) to construct implant prosthesis.((16-17) 2)

Zirconia is a polycrystalline ceramic without any glass component. It is found in three forms, the monoclonal form at room temperature, tetragonal form when heated to 1170 degree and cubic form when heated to 2370 degree. On cooling, the tetragonal phase transforms to the monoclinic phase at 100 degrees below 1170. A very important property of zirconium was found that when crack forms in the tetragonal form, the material transforms into thermodynamically more favorable monoclinic form, with an increase of volume of 4%. This produces a clamping effect on the crack and stops its further propagation and this property is known as transformational toughening (11,18)

There are three types of zirconia in dental industry, the fully sintered or HIP (hot isostatic pressuring), partially sintered and non-sintered (green state) types. Three of them are chemically identical, but have slightly different physical properties, which may or may not be clinically significant. The first type utilizes high temperatures and pressures to create high-density material. The second and third types both considered (non HIP zirconium) due to similar manufacturing processes are made of blocks that are softer due to partial sintering and therefore are easier in milling procedures and later completely sintered in furnace to achieve their final physical and mechanical properties (19)

BioHPP (High Performance Polymer) is a PEEK remodel that has been specially adjusted for the use in the dental field. Owing to it’s strengthening with special ceramic filler, superior mechanical properties have been developed for dental technical and/or dental medical use in the fixed prosthodontics area. This ceramic filler has a grain size of 0.3 to 0.5 μm. due to this immensely small grain size, constant homogeneity can be reached. This homogeneity is an essential prerequisite for these superior material properties and forms the basic grounds for consistent and reproducible quality. The minute granularity of the filer is the main reason behind the extremely good polishing properties that emerge later. The accumulation of plaque is hindered and the degree of pigmentation is reduced owing to the fact that the surfaces are polished to a high shine (20),

The superior physical properties mean that BioHPP material can recently be used as a framework material for prosthetic restorations. The material may be relatively new to market, but we believe it has huge potential for upcoming success in the future. The applications are diversified; whether for a bridge framework, full anatomical restorations, or secondary structures (telescopes, bars), it is possible to address all these prosthetic indications using BioHPP. We have been researching for an alternative procedure to secondary structures made of non-precious metal. ((21)

The maximum fracture resistance indicates the value of force – measured in Newtons - at which the sample fails (4-part Bridge on human stumps in our trial structure). Values of up to 1200Newtons were reached during testing, which, when compared to the maximum biting force of 500 Newtons for a human bite, represents an acceptable safety margin. (22)

The E-modulus of BioHPP lies in the range of 4000 MPa, (while that of Zirconia is 205 GPA), which very strongly resembles the elasticity of human bone (e.g. in the mandible). The chewing forces are therefore cushioned, even with implant-supported bridges.(20) Thus this research is proposed to evaluate which material is less destructive to the supporting structures using strain guage analysis.

MATERIALS AND METHODS

An educational stone model of completely edentulous mandibular arch was used as a template for the acrylic test model construction. All the undercuts in the educational model were blocked using modelling base plate wax. An impression of the modified educational edentulous stone model was made using silicon rubber base impression material (Speedex, Putty consistency, Polysiloxane, Coltêne Whaledent, France) to obtain cast in wax that was pressed into heat cured acrylic resin model.

Implant insertion

The waxed up denture was made and seated on the cast and a mark was made on the cast with a marker between the canine and first premolar on each side. The mark was extended to the crest of the ridge anteriorly.

An orthodontist wire was adapted to conform the arch curvature, and the marks on the ridge crest were transferred to the wire. The wire was straightened, the distance between the two marks measured and divided by four. The wire re-curved to conform the arch curvature and the four equidistant marks transferred to the cast, indicating the locations of the four implants. Drilling was made in the proposed implant regions. The four two pieces reactive implants system (3.7 mm in diameter and 13 mm in length[**]tri-lobe implant, Nobel Replace™ , USA) were fixed in place using self cure acrylic resin using a dental surveyor with straight hand piece.

Simulation of the oral mucosal layer

A stone index was made covering the denture bearing area, labial, buccal and lingual vestibules and tongue space of the model. After setting, the index separated from the cast. A round bur of 2 mm thickness was used to make a uniform reduction of the denture bearing area and limiting borders.

Thin layer light body rubber base (zetaplus, zhermack, Italy)was placed over the reduced edentulous area and stone index was repositioned in its previous position to produce an even thickness of the light body, until setting of impression material.

Installation the scan bodies of the implants and construction of a 3D scan models

After the scan bodies were screwed to the implants in a parallel manner using the screwdriver and the self-retaining screw of the scan body was properly engaged to pick up the screw. Scan body with the screw was mounted to the implant by the screwdriver to tighten the self-retaining screw. After screwing, Scan bodies were checked that they were completely aligned with the retention features of the abutment and that the Scan bodies is seated properly in a parallel manner by the dental surveyor in order to avoid deformation or inaccurate scan information regarding the positioning of the implant.

Scanning of the cast model

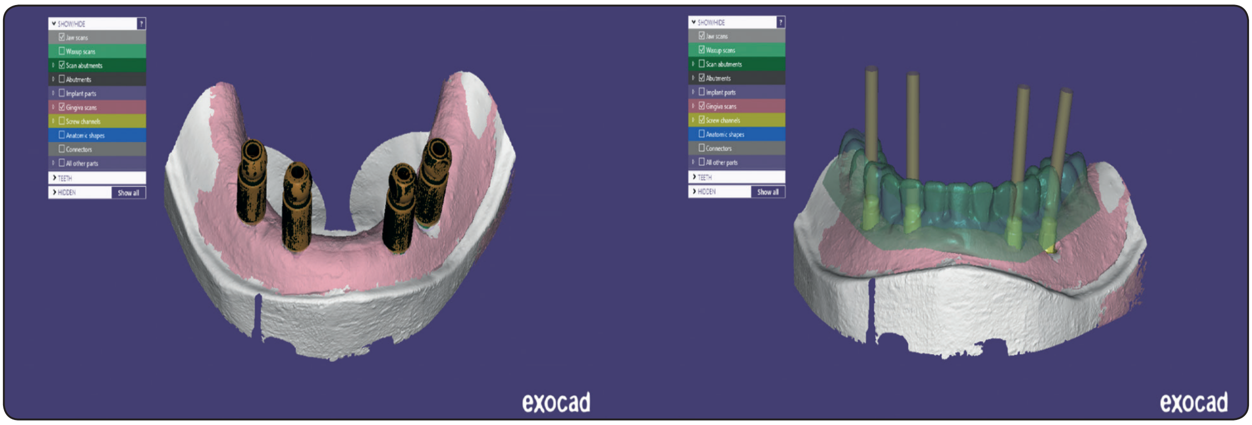
The model cast with the scan bodies mounted to the implants was fixed to the 3D scanner magnetic table in zero tilt and was put on the lower metal plate of the the 3D tabletop digital scanner[*] (Identica blue, Medit, Korea). The model was scanned to create 3D scan model. A 3D scan model was used to design the implant supported fixed bridge by the technician using the ExoCAD software[**] system.

Prosthetic design

After construction of a 3D scan model, prosthetic designs was proceeded on the scan model

Once the scanning data had been exported to the planning software, the relevant anatomical structures could be visualized with the 3D representation and the implants positioned in exactly the right place from a prosthetic and anatomical perspective

The implant fixed bridge was designed in a cut back framework design as it was veneered with its corresponding veneering material.



SHOW/HIDE ?
☑ Jaw scans
☐ Waxup scans
☑ Scan abutments
☐ Abutments
☐ Implant parts
☑ Gingiva scans
☐ Screw channels
☐ Anatomic shapes
☐ Connectors
☐ All other parts
TEETH
HIDDEN Show all

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☐ All other parts
TEETH
HIDDEN Show all

Fig. (1) Screen shots showing (A) scan bodies in place (B) restoration design showing screw channels

Milling of BioHPP implant retained fixed bridge

After finishing the proper cut back framework design, the framework was milled from BioHPP blank (breCAM.BioHPP Ø 98,5 mm with 20 mm fold) by a 5 axis milling machine (S1,VHF, Germany).

After milling, the BioHPP blank was removed from the milling machine and the holding sprues for the implant bridge were separated from the BioHPP framework, then finished and polished.

Veneering of framework was performed using composite material. Formulation of the gingival sections with pink composite (bredent, Spain) was also performed.

Fig. (2) Milled BioHPP framework

Milling of zirconia fixed bridge

The same CAD design was used for production of zirconia implant retained bridge (Bruxzir, Glidwell laboratories, USA) with same milling machine after insertion of enlargement factor in CNC machine. Then silicon index material* was constructed on the buccal surface of the BIOHPP fixed bridge to be used while veneering the zirconia framework with veneering porcelain (VM 7)

Installation of Strain gauges

The strain Guages (Kyowa electronic instrumentco, LTD Tokyo,Japan) were supplied with fully encapsulated grid and attached wires insulated by packing material. Guage length was 2mm, guage resistance was 120.4 and guage factor was 2.09%.

A fissure bur was used to create a groove 1mm on the distal aspects of the terminal implants. Where a flat plane parallel to the long axis of the implant was created to receive strain gauges. Two strain gauges were installed on the distal side of implants.

Load application and recording of microstrains

Vertical unilateral loading starting from zero up to 100 N was applied by the straight load applicator bar of the universal testing machine (LIoydo LR5K, Hampshire, UK, operated using software nexygen version 4.6) touch the central fosse of right first molar as unilateral axial and 45 off-axial loads

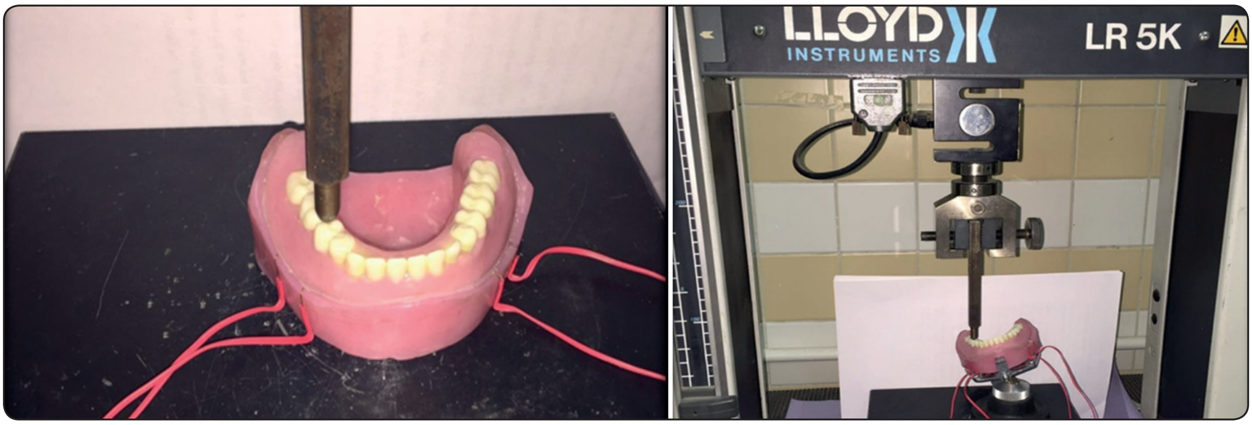

Fig. (3) Unilateral (A) Axial load (B) Off axial load

The microstrains were recorded to measure the strains developed at the distal aspect of each implant. Once the load was applied the microstrains readings were transferred to microstrains unit from the strain meter. Enough time was elapsed (15 minutes) between each two successive measures to allow complete rebound of the resilient structures. The same steps were followed for design II.

The obtained data was inspected to detect the sudden drop of the measured microstrains. The mean of the last ten readings obtained from each channel before the incidence of sudden drop of the measured microstrains were tabulated for statistical analysis to compare between strains obtained from the two restorations.

Statistical analysis

Instat for windows, version 3.036 (Statistical Services Center,University of Reading, UK) was used for data analysis. Student-t-test was used to compare the amount of strains developed on the peripheral implants after application of unilateral loading (axial& off axial) on BioHPP fixed bridge and Zirconia fixed bridge. The significance level was set $p \leq 0.05$

RESULTS

Under unilateral axial load

TABLE (I) Mean, standard deviation and results of student-t-test of the strains developed from unilateral axial loads on fixed bridges.

	BioHPP F bridge		Zirconia F bridge		p-value
	Mean	± S.D	Mean	± S.D	
Right side Loaded	105.85	17.49	151.28	55.38	0.064
Left side Unloaded	76.07	6.86	142.14	31.09	0.063

The result obtained from table I showed that the greatest microstrains were induced on implants supporting zirconia bridges. However by using student T-test to compare the amount of microstrains induced under BioHPP fixed bridge and zirconia fixed bridge there was a statistically insignificant difference between them on the loaded and unloaded implants.

Under unilateral off-axial load

TABLE (II) Mean, standard deviation and results of student-t-test of the strains developed from unilateral off axial loads on fixed bridges.

	Biohpp F bridge		Zirconia F bridge		p-value
	Mean	± S.D	Mean	± S.D	
Right side Loaded	162.14	11.52	183.85	31.42	0.11
Left side Unloaded	114.42	18.43	136.7	26.33	0.099

The result obtained from table II showed that the greatest microstrains were induced on implants supporting zirconia bridges. By using student T-test to compare the amount of microstrains induced under BioHPP fixed bridge and zirconia fixed bridge there was a statistically insignificant difference between them on the loaded implants and the unloaded one.

DISCUSSION

Implants and natural teeth respond differently to masticatory forces,(23,24) and these differences were related to the existence or absence of periodontal ligaments, which serve as an elastic buffer.(25) Analyzing the biomechanical responses of these structures is challenging because of the complexity of biomaterials, dental anatomy, and microstructural details.(26,27)

This in-vitro study was conducted to evaluate and compare the stresses induced on implant supporting structure for either BioHPP or zirconia implant supported fixed partial denture using stain gauge analysis. The traditional methods of evaluation used in dentistry were either in vitro using models, or in vivo through clinical evaluation. This study was carried out in vitro to allow for better control over variables and to facilitate measurements of changes, which occur. Clinical evaluation is not sufficient to detect the relative requirements of any particular philosophy. In vitro study was carried out, as it seemed beneficial in providing valid comparative data excluding the effect of variation in the nature of the tissues overlying the ridge and the form and quality of residual ridge. In addition variation of oral hygiene, strength of masticatory muscle, age and sex are factors representing further difficulties to reach definite result in the clinical evaluation (28). Accordingly, this study was carried out in- vitro to omit human variation and to produce more realistic results.

BioHPP material was used because the physiological properties of this framework material are surpassed only by nature itself. BioHPP allows patients to forget that they are wearing a restoration, as it is just as elastic, stable and light as bone, with the same thermal conductivity, wide range of indications from an individual abutment to large tertiary constructions for permanent or removable, high quality prosthetic treatments on implants or natural teeth (29).

In the present study, the intensities of vertical and oblique loads were not equal because the total vertical load, which was applied to the central fossa, was divided into buccal and palatal cusps, and the oblique load was directly applied to the palatal cusp.(30) Moreover, oblique loads have been reported to increase stress values in peripheral bone and prosthetic components.(31) Similarly, in the present study, oblique load generated great stress in the crown, implant, abutments, and cortical bone. A wide range of loads between 17 and 450 N is observed during mastication.(32) Therefore, Occlusal interferences must be eliminated, and an optimum occlusal relation should be established for long-term survival.

The Young modulus, also known as the elastic modulus, is one of the important factors determining a material's behavior.(33)

Results of the present study revealed that both restorative crown materials had similar biomechanical behavior in terms of stress distribution in implants and peripheral bone. Therefore, the hypothesis that BioHPP restorations would produce favorable stress values in implants and peripheral bone was rejected.

The low level of the elastic modulus of PEEK material is thought to provide insufficient support and generate more stress on the surrounding structure.(34) Studies evaluating the effect of material on stress distribution have mostly focused on titanium and zirconia abutments, and the results were contradictory.(35-37)

Moreover, Bassit et al(38) supported these results in their in vivo study. Wang et al(39) stated that the total energy transferred to the implant-bone interface was similar, although restorative crowns made of different materials might show different amounts of displacement. Similar biomechanical responses were observed in the present study. Although resin-matrix ceramics have been proposed as shock-absorbing materials,(40-42) a substantial decrease was not observed in the stress concentrations of implants and peripheral bone. Several layers or structures play a role in transmitting masticatory forces to implants and peripheral bone, including the restorative crown, cement layer, inner screw, and abutment43 The total energy transferred to the implant-bone interface first passes through the abutment-implant interface.(39) Some of the transmitted energy is considered to be absorbed by the intermediate structures. This may explain the similar biomechanical responses in implants with different superstructure materials.

CONCLUSION

Based on the present in vitro results, the following conclusions were drawn:

1. The change in restoration material did not affect the stress distribution in implants and peripheral bone.
2. Oblique load resulted in high stress concentrations.

REFERENCE

1. Gunnar E. Carlsson:Responses of Jawbone to Pressure. Gerodontology, 2004 ;21(2):65-70.
2. Jemt T: Implant Treatment in Elderly Patients. Int J Prosthodont. 1993;6(5):456-61.
3. Olsson M, Gunne J, Astrand P, Borg K: Bridges Supported by Free-Standing Implants versus Bridges Supported by Tooth and Implant. A Five-Year Prospective Study. Clin Oral Implants Res. 1996;6(2):114-21.
4. Carlo Paolo Marinello Nicola Ursula Zitzmann: A Review of Clinical and Technical Considerations for Fixed and Removable Implant Prostheses in the Edentulous Mandible. Int J Prosthodont. 2002;15(1):65-72.
5. Chee. W and Jivraj .S: Treatment Planning of the Edentulous Mandible. Br Dent J. 2006, 23;201(6):337-47.
6. Jaafar Abduo, Bennani V, Waddell N: Assessing the Fit of Implant Fixed Prostheses: A Critical Review. Int J Oral Maxillofac Implants. 2010;25(3):506-15.
7. Matthias Karl: Fixation of 5-Unit Implant-Supported Fixed Partial Dentures and Resulting Bone Loading: A Finite Element Assessment Based on in Vivo Strain Measurements. Int J Oral Maxillofac Implants. 2006;21(5):756-62.
8. Karl M and Holst S: Strain Development of Screw-Retained Implant-Supported Fixed Restorations: Procera Implant Bridge versus Conventionally Cast Restorations. Int J Prosthodont. 2012;25(2):166-9.
9. Minkle Gulati, Vishal Anand, Sanjeev Kumar Salaria, Nikil Jain, and Shilpi Gupta: Computerized implant-dentistry: Advances toward automation. J Indian Soc Periodontol. 2015; 19(1): 5–10.
10. Persson A, Andersson M, Oden A and Sandborgh-ENGLUND G: A three-dimensional evaluation of laser and a touch-probe scanner. J of Prosthetic dentistry;2006:95,194
11. Pilathadka S.,Vahalova D. and Vosahlo T.: The Zirconia :a new dental ceramic material. Anoverview.Prague Med Rep.;2007:5,108
12. Ariko K,: Evaluation of the the marginal fitness of tetragonal zirconia polycrystal all ceramic restorations. Kokubyo Gakkai Zasshi.2003;70:114.

13. Hertlein G.,Hoscheler S. and Frank S., etal: Marginal fit of cad/cam manufactured all ceramic zirconia prosthesis J.Dent.Res;2001:80.

14. Keough B,Kay H and Sager R, A ten-unit all ceramic anterior fixed partial denture using Y-TZPzirconia.Pract Proced Aesthet Dent;2006:18,37 on net

15. Strub J. R. and Beschnidt S. M: Fracture Strength of 5 Different All-Ceramic Crown Systems. Int J Prosthodont. 1998;11(6):602-9.

16. kapos T, Ashy LM, Gallucci GO, Wismeijer D: Computer-Aided Design and Computer-Assisted Manufacturing in Prosthetic Implant Dentistry. Int J Oral Maxillofac Implants. 2009;24 Suppl:110-7.

17. Richard van Noort: The Future of Dental Devices Is Digital. Dent Mater. 2012;28(1):3-12.

18. Parker r.: Use of zirconia in restorative dentistry. Dentistry Today;2007,114

19. Guazzato M., Albakry M., Ringer S.P. and Swain M.V.: Strength, fracture toughness and microstructure of a selection of all ceramic materials.Part II. Zirconia-based dental ceramics.Dental materials:official publication of the Academy of Dental Material:2004;20,449

20. Rzanny A, Göbel R, Fachet M: BioHPP summary of results for material tests. Research report for Bredent (Senden) Jena university, 10, 2013

21. Fink, Johannes Karl ‚High Performance Polymers A2," in High Performance Polymers (Second Edition).William Andrew Publishing.USA. 06;2014

22. B. Siewert, M. Parra: A new group of materials in dentistry: PEEK as a framework material for 12-piece implant-supported bridges. Z Zahnärztl Implantol. 2013;29:148–159.

23. Ishigaki S, Nakano T, Yamada S, Nakamura T, Takashima F.: Biomechanical stress in bone surrounding an implant under simulated chewing. Clin Oral Implants Res 2003;14:97-102. 3

24. Pesqueira AA, Goiato MC, Filho HG, Monteiro DR, dos Santos DM, Haddad MF, et al.: Use of stress analysis methods to evaluate the biome-chanics of oral rehabilitation with implants. J Oral Implantol 2014;40:217-28. 4

25. de Kok P, Kleverlaan CJ, de Jager N, Kuijs R, Feilzer AJ. Mechanical per-formance of implant-supported posterior crowns. J Prosthet Dent 2015;114: 59-66. 8

26. Güngör MB, Yılmaz H. Evaluation of stress distributions occurring on zirconia and titanium implant-supported prostheses: a three-dimensional finite element analysis. J Prosthet Dent 2016;116:346-55. (50)

27. Lin D, Li Q, Li W, Swain M. Dental implant induced bone remodeling and associated algorithms. J Mech Behav Biomed Mater 2009;2:410-32. (56)

28. Cekic C, Akca K,& Cehreli MC: Effects of attachment design on strains around implants supporting overdentures. Quintessence Int. 2007;38:291-297. (152)

29. Fink, Johannes Karl ‚High Performance Polymers A2," in High Performance Polymers (Second Edition).William Andrew Publishing.USA. 06;2014. (119)

30. de Faria Almeida DA, Pellizzer EP, Verri FR, Santiago JF Jr, de Carvalho PSP. Influence of tapered and external hexagon connections on bone stresses around tilted dental implants: three-dimensional finite element method with statistical analysis. J Periodontol 2014;85:261-9. (6)

31. Takahashi JMFK, Dayrell AC, Consani RLX, de Arruda Nobilo MA, Henriques GEP, Mesquita MF. Stress evaluation of implant-abutment con-nections under different loading conditions: a 3D finite element study. J Oral Implantol 2015;41:133-7. 58

32. Morneburg TR, Pröschel PA. Measurement of masticatory forces and implant loads: a methodologic clinical study. Int J Prosthodont 2002;15:20-7. 59

33. Della Bona A, Corazza PH, Zhang Y. Characterization of a polymer-infiltrated ceramic-network material. Dent Mater 2014;30:564-9. 53

34. Schwitalla AD, Abou-Emara M, Spintig T, Lackmann J, Muller WD. Finite element analysis of the biomechanical effects of PEEK dental implants on the peri-implant bone. J Biomech 2015;48:1-7. 26

35. Peixoto HE, Bordin D, Del Bel Cury AA, da Silva WJ, Faot F. The role of prosthetic abutment material on the stress distribution in a maxillary single implant-supported fixed prosthesis. Mater Sci Eng C Mater Biol Appl 2016;65: 90-6. 43

36. Carvalho MA, Sotto-Maior BS, Cury AADB, Henriques GEP. Effect of plat-form connection and abutment material on stress distribution in single anterior implant-supported restorations: a nonlinear 3-dimensional finite element analysis. J Prosthet Dent 2014;112:1096-102. 44

37. Çaglar A, Bal BH, Karakoca S, Aydın C, Yılmaz H, Sarısoy S¸. Three-dimensional finite element analysis of titanium and ytryum-stabilized zirconium dioxide abutments and implants. Int J Oral Maxillofac Implants 2011;26:961-9. 45

38. Bassit R, Lindström H, Rangert B. In vivo registration of force development with ceramic and acrylic resin occlusal materials on implant-supported prostheses. Int J Oral Maxillofac Implants 2002;17:17-23. 61

39. Wang TM, Leu LJ, Wang JS, Lin LD. Effects of prosthesis materials and prosthesis splinting on peri-implant bone stress around implants in poor-quality bone: a numeric analysis. Int J Oral Maxillofac Implants 2002;17:231-7. 40

40. Fasbinder DJ, Neiva GF. Surface evaluation of polishing techniques for new resilient CAD/CAM restorative materials. J Esthet Restor Dent 2016;28:56-66. 19

41. Schepke U, Meijer HJA, Vermeulen KM, Raghoebar GM, Cune MS. Clinical bonding of resin nano ceramic restorations to zirconia abutments: a case series within a randomized clinical trial. Clin Implant Dent Relat Res 2016;18: 984-92. 20

42. Awada A, Nathanson D. Mechanical properties of resin-ceramic CAD/CAM restorative materials. J Prosthet Dent 2015;114:587-93. 21

43. Sevimay M, Usumez A, Eskitascıoglu G. The influence of various occlusal materials on stresses transferred to implant-supported prostheses and sup-porting bone: a three-dimensional finite-element study. J Biomed Mater Res B Appl Biomater 2005;73B:140-7. 14