Biomechanical Evaluation of Different Implant Positions when Restoring the Maxilla: A Finite Element Analysis

Livia Forster Ribeiro[1], Marco Aurélio de Carvalho[2],Bruno Salles Sotto-Maior[3], Altair Antoninha Del Bel Cury[4]

[1]Department of Biomaterials Research Unit and Innovative Interfaces, University of Paris Descartes, Île de France, France.
[2]Department of Stomatology, Federal University of Goiás, Brazil.
[3]Department of Restorative Dentistry, Federal University of Juiz de Fora, Brazil.
[4]Department of Prosthodontics and Periodontology, Piracicaba Dental School, State University of Campinas, Brazil.

*Abstract***—***The absence of four upper incisors is a complex and delicate treatment challenge. The fewer implants are placed into the arch is easier to restore esthetically. However biomechanical principles could be jeopardized. This study evaluated the biomechanical behavior on a fixed prosthesis supported by different number and position implants in the anterior maxilla. Four different models, 4 implants supporting four splinted crowns (4l); implants in central incisors as support and lateral incisor as cantilevered elements (CS); one implant in central and one lateral incisors as support, with a pontic and cantilevered crowns (CSLS) and implants in lateral incisors as support and central incisors as pontics (LS) were analyzed by finite element analysis (FEA). The implants received mini conical abutment and zirconia screwed prosthesis. A magnitude force of the 37.5N was applied on each palatal surface of the incisors with 45°angle to the long axis of the implants. The reduction of number of implants increased von Mises stress in all components. Lower values of von Mises stress were observed in the 4I model. In the models with two implants, the CS model showed lower von Mises stress except in framework that is in CSLS model. The study concluded that the number of implants influence in biomechanical behavior and when reduce implant number to enhance esthetically anterior rehabilitation the CS and CSLS models showed better biomechanical behavior.*

*Keywords***—***Dental implants, dental prothesis, finite elements analysis.*

I. INTRODUCTION

Oral rehabilitation with dental implants in the anterior maxilla is still a challenge due to the high esthetic requirement.1 Currently, the treatment success with implant-supported prosthesis requires understanding of the basic biomechanical principles combined with the dentist surgical skills and the capability of satisfying the patient's functional and esthetics demands[2].

An essential prerequisite for a predicable implant-supported rehabilitation is the adequate bone availability[3]. The buccal-lingual ridge dimension should be enough to provide approximately a 2mm-thick buccal and lingual bone walls around the implant, as well as enough mesiodistally[4].In many clinical situations the anterior maxillary ridge is highly resorbed, making it unpractical restore with single crown implant-supported restorations[5]. Conventionally, the distance between implants (external or internal hexagon connection types) must be of at least 3mm, in order to ensure the preservation of crestal bone[6].

However, the required distance between implants decreases when using morse taper connection, preserving the interimplant crestal bone more efficiently[7]. A common approach to rehabilitate atrophic anterior maxilla is through the use of two implants to support four crowns (either pontics or cantilevers), optimizing the esthetic outcomes in the anterior section[8,9]. However, the reduction in the number of dental implants may increase the risk of mechanical failures such as prosthetic screw loosening and fracture of implant, abutment, framework or veneering ceramic[6,9].

The use of two implants to support a four elements partial prosthesis may enable better handling of the soft tissue in the pontic area, enhancing the cervical embrasures and reducing the black triangle appearance in the more esthetic demanding region of anterior maxilla[10]. However, two implants may jeopardize the biomechanical behavior of the system, as fewer implants supporting a prosthesis may

increase the concentration of stress in the perimplantar region[11].

The understanding of stress concentration and dissipation in different implant number and configuration options may provide more evidence to the decision-making process when restoring the anterior edentulous section. This analysis is crucial due to the inherent oblique loading in the anterior section and the possible use of suspended elements in the restoration (pontics and cantilevers) that may increase the risk of biomechanical failure[12].

Due to the absence of the substantive data that evaluated the mechanical behavior of the components on different implant configurations, the analysis of different positions and number of implant in the prosthetic rehabilitation is still needed to find out the most predictable treatment[13].Therefore, the aim of this study was to evaluate the biomechanical behavior of the fixed partial prosthesis in different positions of implants in the anterior maxilla using the three-dimensional finite element method.

II. METHOD

2.1 Experimental Design

In order to reproduce a clinical situation of the absence of four maxillary incisors restored with four-unit fixed partial prosthesis (FPP) supported by implants, four models using a three-dimensional computer-aided design software (SolidWorks 2013 Corp., Concord, MA, USA) were created. Each model consisted of dental implants supporting four elements restoration with four different arrangements: 4 implants model supporting four crowns splinted (4I); implants in central incisors as support and lateral incisor as cantilevered elements (CS); one implant in central and one lateral incisors as support, with a pontic and cantilevered crowns (CSLS) and implants in lateral incisors as support and central incisors as pontics (LS) as seen in Fig. 1. Finite Element Analysis (FEA) was used to determine the stress values in the restorations for all models.
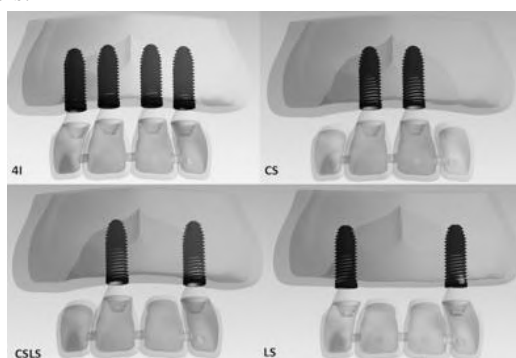

Fig. 1: 4I, CS, CSLS and LS models. Different positions of the implants and corresponding prosthesis.

2.2. Model Construction

A section of the anterior maxilla of a completely edentulous patient (volunteer) and natural maxillary central incisors were obtained in the laboratory of images of finite elements of the Faculty of Dentistry of Piracicaba (FOP -UNICAMP) library. The maxillary bone including cortical and trabecular layers and also the anatomy of upper incisors (prosthetic crowns) were obtained by cone beam CT images (CTCB) (i-CAT Cone Beam 3D Dental Imaging System, Imaging Sciences International). The images CTCB were transferred to In Vesalius 3.0 (Center for Information Technology Renato Archer) software for 3D (three dimensions) image reconstruction from a sequence of DICOM 2D (two dimensions) images (Digital Imaging and Communications in Medicine). Afterwards, all the images were exported to the CAD (Computer Aided Design) software SolidWorks® (SolidWorks Corporation 2013, Concord, MA, USA) and the 3D solid models were obtained. In order to simulate a challenging scenario in which the anterior maxilla is severely resorbed (atrophic anterior maxilla), an edentulous ridge was used as a reference for a partially atrophic edentulous maxilla.

The physical measures of the implants and prosthetic components regarding their diameter (D), height (H) and length (L) of the implants and 3D prosthetic components were designed in the CAD / SolidWorks® software and based on the characteristics of the materials applied. Likewise, the reconstructed had shown maxilla showed the following dimensions: 27mmx20mmx10mm (L / H / D). The bone in the anterior maxilla was classified as type 3 represented by a thick layer of cortical bone surrounding a core of dense trabecular bone, as described by Lekholm& Zarb[14]. The implants with a Morse taper interface (dimensions: 3.75x11mm Titamax CM/EX Neodent, Curitiba- Brazil) as well as the prosthetic components (mini type conical abutment - Mini Conical Abutment CM, Neodent, Curitiba, Brazil) consisted of a titanium alloy TiA6V4[15]were used in the models.

A zirconia prosthetic framework was, then, manufactured based on the anatomic area of the maxillary bone and the shape of the prosthetic crowns of the upper incisors (dimensions of the connector: 4x4mm). Feldspatic ceramic was employed to veneer in the prosthetic crowns. The crowns, abutments, implants were considered to be isotropic, homogenous and linearly elastic[16,18] and cortical and trabecular bone were considered to be anisotropic, homogenous and linearly elastic. The mechanical properties (modulus of elasticity or Young's modulus, shear modulus and Poisson's ratio) of these structures are shown in Table 1.

Table 1- Mechanical properties of materials

TABLE 1

		Young's modulus (E) (MPa)	Shear modulus (G) (MPa)		Poisson ratio (δ)
Cortical bone [5,6,25]	E_x	12,600	G_{xy}	4,850	δ_{xy} 0.30
	E_y	12,600	G_{yz}	5,700	δ_{yz} 0.39
	E_z	19,400	G_{xz}	5,700	δ_{xz} 0.39
Trabecular bone [16,25]	E_x	1,150	G_{xy}	6,800	δ_{xy} 0.001
	E_y	2,100	G_{yz}	4,340	δ_{yz} 0.32
	E_z	1,150	G_{xz}	6,800	δ_{xz} 0.05
Titanium (Implant and Abutment) [5,6,25]		104,000		38,800	0.34
Zirconia [25]		210,000		33,000	0.31
Ceramic Crowns [7,9,25]		70,000		40,000	0.30

2.3. Numerical Analysis

The models were exported to the software ANSYS Workbench 14.0 (Swanson Analysis Systems Inc. Houston / PA, USA) in order to obtain the mesh and its subsequent numerical analysis. From the mesh standpoint, the quadratic tetrahedral elements with 3 degrees of freedom per node, consisting of 0.5 mm each one, were then generated. In order to increase the accuracy of the models, a mesh refinement process was performed by the analysis of convergence (5%). The models presented a number of elements ranging from 290.203 to 177.992, and a number of nodes ranging from 501.571 to 310.143 in each model. The boundary conditions were established in the outer superior and posterior surfaces of the models in all directions.

The "bonded type" contact was used in this linear analysis. The bone/implant interface was assumed as in a perfect union, simulating a complete osseointegration. In addition, the set of abutments, framework and crowns were completely splinted. During the analysis, no sliding or separation was allowed between the interfaces.[14,17] A 150N load was applied in the cingulum areas of the four incisor crowns, 37.5N each. A 45° angle to the long axis of the implants was used to simulate the inherent oblique loading in the anterior region.[18,19]

The ANSYS® software was used to calculate the values of von Mises stress for implants, abutments, framework and ceramic of the prosthetic crowns.

III. RESULTS

The highest values for equivalent von Mises (σvM) stress in all models are presented in the figure 2.

The number of the implants revealed an important influence on biomechanical behavior proved by lower equivalent von Mises stress in all components evaluated into the group 4l as seen in figure 2.
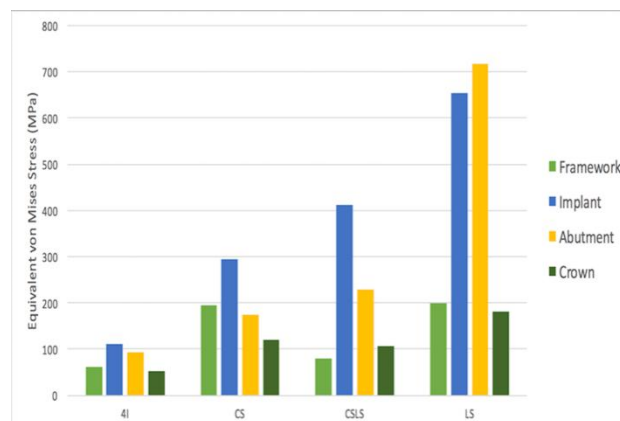

Fig. 2: The equivalent von Mises stress values (MPa) and the components of the models.

The analysis von Mises stress in the implants showed, in all models, that the prevalence of the stress on the buccal side was predominantly in the inner surface of the conical prosthetic connection as seen in Fig. 3. The stress was concentrated in the first threads on the implant and decreasing towards the implant apex, regardless the implants arrangement. The higher σvM stress concentration was found in LS model (654 MPa), following the CSLS model (412 MPa) and CS model (295 MPa). The model 4l showed lower stress concentration values with peak the 112 MPa.
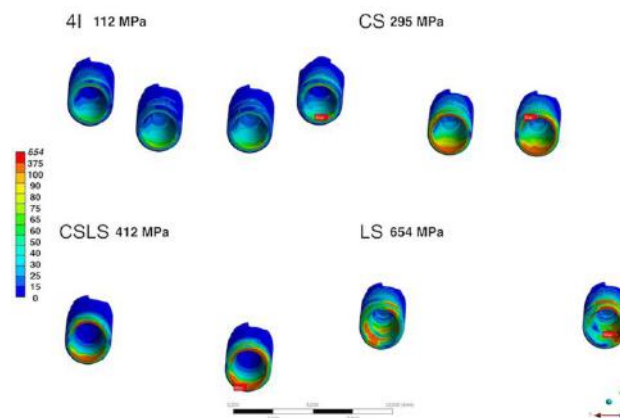

Fig. 3: The von Mises stress (MPa) in the dental implants.

In the abutments all models showed stress concentration on the buccal surface at the implant platform contact, except the LS model showed the stress in all abutment body with the highest value stress (716 MPa). The CSLS (228 MPa) and CS (174 MPa) models had a similar biomechanical behavior as seen in Fig. 4.
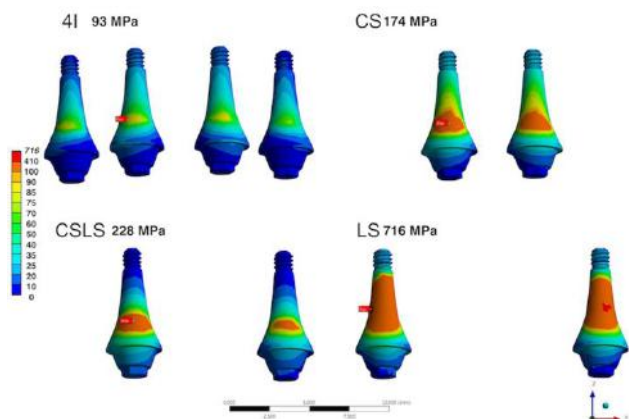
Fig. 4: The von Mises stress (MPa) in the abutments.

Fig. 6: The von Mises stress (MPa) in the ceramic crowns.

When analyzing the frameworks, the von Mises σvM stress values were concentrated in the connector area in all models as seen in Fig. 5. The highest values were found in LS model (200 MPa) and the lowest values in the 4I model (61 MPa). The CS and CSLS models showed similar the von Mises values.
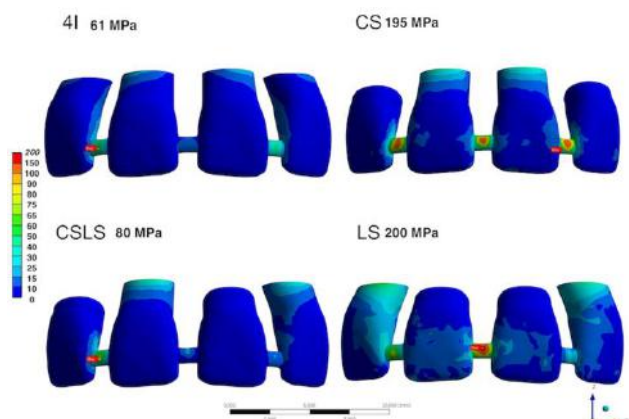

Fig. 5:he von Mises stress (MPa) in the frameworks.

The similar results of frameworks, the ceramic prostheses showed the equivalent von Mises stress values were concentrated in the connector area in all the models Fig. 6. The highest values were found in LS model (182 MPa) and the lowest in 4I model (53 MPa). The CS and CSLS models showed the von Mises values similar, 121 and 108 MPa respectively.
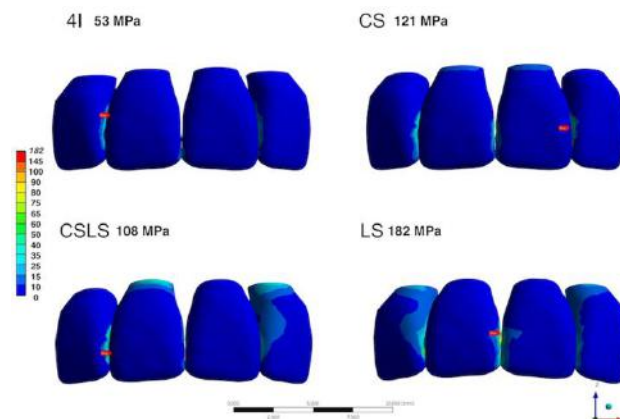
4. Discussion

The positioning of the implants in the anterior region raises several issues ranging from bone quality to the long-term maintenance of the implants, since it is located in a region with a high aesthetic and mainly functional requirement.[20]The successful treatment with Osseo integrated implants depends on the ability to satisfy patient's functional and esthetics demands.[2,31] Considering this, it is important to study the position and the number of implants in a fixed partial denture, since this have an important role in the mechanical behavior of prosthetic rehabilitation. This study may provide biomechanical information to clinicians to aid the treatment planning regarding implant amount and distribution in the anterior maxilla. Also, an insight is provided on the biomechanical risk and stress concentration on the obliquely loaded restoration and implants.

The "bonded type" contact has been extensively used in finite element analysis in dental research despite the fact of not simulating the real clinical condition.[21-23] This simplification does not jeopardize the results of the study as it was conducted during the linear regimen of the structures during the numerical analysis. Thus, as a complete Osseo integration is simulated, the "bonded type" contact may be justified. The contact between implant, abutment and restoration was also considered bonded as the aim of this study was to evaluate the stress dissipation and not the gap formation between components.[24-27]The loading condition used in the present study was based in the occlusal contact points existing within the normality of mandibular movements for the anterior teeth observed in several studies. [9,12,15,28]As the force applied on the restoration is in agreement with the loads exerted in this region, it allows the materials to undergo elastic deformation.

The materials of the structures analyzed have elastic behavior at the applied load regimen, which further

undermines the use of linear simulation. The use of the von Mises fault criterion is more applicable when observed in ductile materials, as in the case of metals.[29] As in this study we observed the tensions in the implants and abutments, the use of the von Mises criterion was justified.[30]

In the development of an FE model, the assumptions regarding material properties, loading conditions, model accuracy, and stress criteria are important for analysis. In the present study, trabecular and cortical bones were assumed to be anisotropic, a propriety, which has been, neglected in other FEA studies.[6,7,9]

The loading conditions assumed a force of 150 N divided among four upper incisors applied at cingulum with 45-degree angle to long axis of tooth to simulate mastication.[18,19] Generating the components from CBCT images and CAD images ensured dimensional accuracy of the models. The results of the present study were in agreement with Dejak and Mlotkowski (2008)[17] the authors of the study reported that von Mises stress might be used to evaluate the behavior of ductile materials such as implants and prosthetics components.

Various implant treatment plans are used for replacement of absence of four upper incisors, varying upon many factors, such as bone quality, space viability and the width of residual ridge. For this condition, the commonly used protocols are either a fixed partial prosthesis supported by two implants to support a four-units prosthesis or a four implants to splinted or unsplinted prosthesis. To improve the esthetics is recommended the use of fewer number of implants,[5,32] however the biomechanical risk may increase.[4,33]

The present study showed that the number and the positioning of dental implants influenced at the mechanical behavior of prosthesis and implants at a four-units upper anterior rehabilitation. Esthetically, it is important to have a certain space between two implants, since it influence on the proximal bone crest level and therefore on the soft tissue volume.[21]

The present study showed that the number of implants influenced biomechanical behavior of four-units upper anterior rehabilitation. When two implants were used in the placement of central incisors as support of lateral incisors as cantilevered elements (CS model) and one implant in central and one lateral incisor as support, with a pontic and cantilevered crowns (CSLS model) the results showed better biomechanical performance than lateral incisors as support and central incisor as pontics.

As an alternative to reduce the overload risk is increasing the number of the implants into the prosthesis. Our results, in accordance with previous studies[6,7] showed that the number of the implants can influence and improve the stability of the implants and prosthetics components. However, others studies, in posterior area under higher load condition stated that the two implants could adequately support a fixed partial prosthesis.[22,23]

In a systematic review[34], all types of fixed implant reconstructions such as implant-supporting single crowns, cantilever partial fixed prostheses or supported partial fixed prostheses (FDPs), non-cantilever, showed 96.8%, 98.5% and 92% of the survival rates. While the implants survival rates are very high, prostheses survival rate is just slightly less favorable with a 5-year survival of 96.3% and 86.5% after 10 years.[34]

Esthetically, fewer implants placed in the arch is easier to restore.[5] Limiting the implant number gives the ceramist more flexibility in designing the prosthesis. Besides that, when restoring multiple teeth with multiple implants, the presence of the bone crest is crucial for the position of the soft-tissue margin in the inter-implant area.[34] The bone crest serves as a foundation for the soft tissues between implants, and loss in height of the proximal bone crest may negatively affect the papillae presence.[35] The distance between two implants may have an influence on the maintenance of the proximal bone crest level.[34,35] Barros et al., 2010[5] in animal studies showed that morse taper implants could be placed in narrow interimplant distance, such as 2mm, which justify its use in the present study, differently from the previous studies that used implants with external connections.[8,9,36]

Following this philosophy our study evaluates three alternatives in the implant rehabilitation for four upper incisors with fewer implants (two). In all the models evaluated, the biomechanical patterns on the implants presented similar concentration in buccal side and in the firsts threads. These results are in agreement with some studies[14,32,37] that explain bone remodeling during the first year of the functional load.

For the prosthetics components, abutments, framework and veneer ceramic, the model LS showed higher stress, specially, on the connectors of the framework. Our data is in accordance with the findings of Bal et al., 2013[20] and Guichet et al., 2002[33], which show an increase of the stresses in the connector's region. Although framework fractures are not common for partial FDPs,[27,38,39] the design used by them influenced on fracture strength of ceramic veneer.[28,40] Our results showed that the presence of stress in the framework correspond to transferred stress to the ceramic veneer. It can be suggested that one of the reasons for the ceramic veneer fractures may be due to the high stresses concentrated in the connector regions.

All the models presented high concentrated stress in the connector surface as the higher von Mises stress was found in the LS model. The highest stress values on the LS model can be explained by reaction forces and bending moments in the framework. The bending moment is the force times the orthogonal distance between the force direction line and the counter-acting support,[29] which is higher in LS model. Therefore, in a long-term follow-up, this kind of FPD could be expected to increase load on the supporting structures.[8]

Despite the present study evaluated different amount of implant and different distribution of implants *in silico* and provided insights on the biomechanical behavior of these combinations, more *in vivo* studies should be carried out in order to observer the clinical effect of such combinations.

IV. CONCLUSION

It was concluded that a higher number of implants interfere positively in both concentration and distribution of stress in all the components of the prosthesis. However, when a reduced implant number is used to enhance aesthetics in anterior rehabilitation, the CS and CSLS models showed better biomechanical behavior.

ACKNOWLEDGEMENTS

REFERENCES

[1] Buser D, Martin W, Belser U. C (2004). Optmizing esthetics for implant restaurations in the anterior maxilla: Anatomic and surgical considerations. *Int J Oral Maxillofac Implants*.; *19* Suppl: 43-61.

[2] Norton M.R(2004). A short-term clinical evaluation of immediately restored maxillary TiOblast single-tooth implants. *The International Journal of Oral & Maxillofacial Implants 19:*274–281.

[3] Tolstunov L, Thai D, Arellano L (2012). Implant-guided volumetric analysis of edentulous maxillary bone with cone-beam computerized tomography scan. Maxillary sinus pneumatization classification. *J Oral Implantol.;38*:377-90.

[4] Camargo I.B, Oliveira D.M, Fernandes A.V, Van Sickels J.E (2015). The nasal lift technique for augmentation of the maxillary ridge: technical note. *Br J Oral Maxillofac Surg;53*:771-4.

[5] Barros R.R, Novaes A.B Jr, Muglia V.A, Iezzi G, Piattelli A(2010). Influence of interimplant distances and placement depth on peri-implant bone remodeling of adjacent and immediately loaded Morse cone connection implants: a histomorphometric study in dogs.*Clin Oral Implants Res.;21*: 371-8.

[6] Wohrle P.S (2014). Predictably replacing maxillar incisors whit implants using 3D planning and guided implant surgery. *Compend Contin Educ Dent;35*:758-62, 764-6, 768.

[7] Vailati F, Belser U. C (2016). Replacing Four Missing Maxillary Incisors with Regular- or Narrow-Neck Implants: Analysis of Treatment Options. *Eur J Esthet Dent; 2*:42–57.

[8] Salama M, Coachman C, Garber D, Calamita M, Salama H, Cabral G (2009).Prosthetic gingival reconstruction inthe fixed partial restoration. Part 2: diagnosis and treatment planning. *In J Periodontics Restorative Dent; 29*: 573-81.

[9] Hasan I, Bourauel C, Keilig L, Reimann S, Heinemann F (2011). The influence of implant number and abutment design on the biomechanical behaviour of bone for an implant-supported fixed prosthesis: a finite element study in the upper anterior region, *Computer Methods in Biomechanics and Biomedical Engineering.;14*: 1113-1116.

[10] BankoğluGüngör M, Yılmaz H. (2016). Evaluation of stress distributions occurring on zirconia and titanium implant-supported prostheses: A three-dimensional finite element analysis. *J Prosthet Dent.;116*:346-55.

[11] Bölükbaşı N, Yeniyol S (2015). Number and localization of the implants for the fixed prosthetic reconstructions: on the strain in the anterior maxillary region. *Med EngPhys;37*:431-45.

[12] Almeida E.O, Rocha E.P, Freitas Júnior A.C, Anchieta R.B, Poveda R, Gupta N, Coelho P.G (2015).Tilted and short implants supporting fixed prosthesis in an atrophic maxilla: a 3D-FEA biomechanical evaluation. *Clin Implant Dent Relat Res.*;17 Suppl 1:e332-42.

[13] Hasan I, Heinemann F, Reimann S, Keilig L, Bourauel C(2011).Finite element investigation of implant-supported fixed partial prosthesis in the premaxilla in immediately loaded and osseointegrated states.*Comput Methods Biomech Biomed Engin.;14:*979-85.

[14] Lekholm U, Zarb G.A. (1985). Patient selection and preparation. In:Branemark P.I, Zarb G, Albrektsson T, editors. Tissue-integrated prostheses. Osseointegration in clinical dentistry. Chicago: *Quintessence Publishing Company Inc*. p. 199-209.

[15] Nayer A. , McGraw-Hill (1997).The Metals Databook. New York, USA.

[16] Sahin S, Cehreli MC, Yaçin E (2002). The influence of functional force on the biomechanics of implant-supported prostheses – a review. *J Dent.;30*: 271-82.

[17] Dejak B, Mlotkowski A (2008). Three-dimensional finite element analysis of strength and adhesion of composite resin versus ceramic inlays in molars. *J Prosthet Dent*; 99:131–140.

[18] Helkimo E, Carlsson G.E, Helkimo M(1977). Bite force and station of dentition. *Acta Odontol Scand.;35*:297-303.

[19] Koostra J.H, van Eijden T.M, Weijs W.A, Naeije M (1988). A three-dimensional mathematical model of the human masticatory system predicting maximum possible bite forces. *J Biomech*; 21:563-576.

[20] Bal BT, Çaglar A, Aydın C, Yılmaz H, Bankoglu M, Atılım Eser A (2013).Finite Element Analysis of Stress Distribution with Splinted and Nonsplinted Maxillary Anterior Fixed Prostheses Supported by Zirconia or Titanium Implants. *Int J Oral Maxillofac Implants;28:*e27–e38.

[21] Dos Santos M. V, Lehmann R.B, de Assis C. C. A, Amaral M, Vitti R.P, Neves A.C.C, da Silva C. L. R (2017). Three-dimensional finite element analysis of occlusal splint and implant connection on stress distribution in implant-supported fixed dental prosthesis and peri-implantal bone. *Mater Sci Eng C Mater Biol Appl.*; 80:141-148.

[22] Corrêa C.B, Margonar R, Noritomi P.Y, Vaz L.G (2014). Mechanical behavior of dental implants in different positions in the rehabilitation of the anterior maxilla. *J Prosthet Dent.; 111(4):*301-9.

[23] Sotto-Maior B.S, Senna P.M, da Silva W.J, Rocha E.P, Del Bel C.A.A (2012). Influence of crown-to-ratio, retention system, restorative material, and occlusal loading on the stress concentrations in single short implants. *Int J Oral Maxillofac Implants.; 27:*e13-8.

[24] Belser U.C, Schmid B, Higginbottom F, Buser D(2004). Outcome analysis of implant restorations located in the anterior maxilla: A review of the recent literature. *Int J Oral Maxillofac Implants;1*9 Suppl: 30–42.

[25] Att W, Yajima N.D, Wolkewitz M, Witkowski S, Strub J.R(2012). Influence of preparation and wall thickness on the resistance to fracture of zirconia implant abutments. *Clin Implant Dent Relat Res*.;14 Suppl 1:e196-203.

[26] Caglar A, Bal B.T, Aydin C, Yilmaz H, Ozkan S(2010). Evaluation of stresses occurring on three different zirconia dental implants: three-dimensional finite element analysis. *Int J Oral Maxillofac Implants.*;25:95-103.

[27] Albakry M, Guazzato M, Swain M.V(2003). Fracture toughness and hardness evaluation of three pressable all-ceramic dental materials. *J Dent.; 31*:181-8.

[28] BankoğluGüngör M, Yılmaz H(2016). Evaluation of stress distributions occurring on zirconia and titanium implant-supported prostheses: A three-dimensional finite element analysis. *J Prosthet Dent.*;116:346-55.

[29] Peixoto H.E, Camati P.R, Faot F, Sotto-Maior B.S, Martinez E.F, Peruzzo D.C(2017).. Rehabilitation of the atrophic mandible with short implants in different positions: A finite elements study. *Mater Sci Eng C Mater Biol Appl.;1:*122-128.

[30] Bordin D. Cavalcanti I.M. Jardim P.M. Fortuna C.A. Sotto-Maior B.S, Del Bel C.A.A.Silva, W. J. (2015). Biofilm and saliva affect the biomechanical behavior of dental implants.*J Biomech.*;*48:*997-1002.

[31] Lan T. H, Du J. K, Pan C. Y, Lee H. E, Chung W-H(2012). Biomechanical analysis of alveolar bone stress around implants with different thread designs and pitches in the mandibular molar area.*Clin Oral Investig;16:*363–369.

[32] Chang M, Wennstrom J. L(2010). Bone alterations at implant-supported FDPs in relation to inter-unit distances: a 5-year radiographic study.*Clin Oral Implants Res. 2010;21:*735-40.

[33] Iplikçioglu H, Akça K(2002). Comparative evaluation of the effect of diameter, length and number of implants supporting three-unit fixed partial prostheses on stress distribution in the bone. *J Dent.;30*:41-6.

[34] Heydecke G, Zwahlen M, Nicol A, Nisand D, Payer M, Renouard F, Grohmann P, Muhlemann S, Joda T(2012). What is the optimal number of implants for fixed reconstruction: a systematic review. *Clin. Oral Implants Res. 23, Suppl. 6*, 217-228.

[35] Cecchinato D, Bengazi F, Blasi G, Botticelli D, Cardarelli I, Gualini F. (2008b). Bone level alterations at implants placed in the posterior segments of the dentition: outcome of sub- merged/non-submerged healing. A 5-year multi-center, randomized, controlled clinical trial. *Clinical Oral Implants Research 19:* 429–431.

[36] Natali A.N, Pavan P.G, Ruggero A.L(2006). Analysis of bone implant interaction phenomena by using a numerica approach. *Clin. Oral Impl. Res. 17;* 67–74.

[37] Guichet D. L, Yoshinobu D., Caputo A. A(2002). Effect of splinting and interproximal contact tightness on load transfer by implant restorations. *J Prosthet Dent.*May;87,5:528-35.

[38] Branemark P.I, Svensson B, van Steenberghe D. (1995) Ten-year survival rates of fixed prostheses on four or six implants ad modumbranemark in full edentulism. *Clinical Oral Implants Research 6:* 227–231.

[39] Kamio S, Komine F, Taguchi K, Iwasaki T, Blatz M.B, Matsumura H(2014). Effects of framework design and layering material on fracture strength of implant supported zirconia-based molar crowns. *Clin Oral Implants Res.* Aug 12.