Investigating The Effect of Trinia and Zirconia Implant Supported Fixed Partial Denture On Stress Distribution in Peripheral Bone: A Three Dimensional Finite Element Modeling

Nabeel Seryoka Martani[1]& Berivan Nawzad Hadi[2]

[1&2]Department of Prosthodontic, College of Dentistry, Hawler Medical University, Erbil, Iraq
Correspondence: Nabeel Seryoka Martani, Department of Prosthodontic, College of Dentistry, Hawler Medical University, Erbil, Iraq
Email: nabeel.martani@hmu.edu.krd

Doi: 10.23918/eajse.v9i1p252

Abstract: Stress transformation from fixed partial denture to dental implant and distribution to surrounding bones is an essential factor in long term survival rate of prosthesis. The main objective of this study was to analyze the effect of a newly developed material (Trinia) and the conventional Zirconia implant-supported fixed partial dentures on stress transformation and distribution in the surrounding bone of dental implants. For this purpose, 3D finite element models of implant supported fixed bridge with surrounding bone were developed and simulated for both Trinia and Zirconia materials subjected to static loading. The results showed that the occlusal load transformed through Trinia and distributed to supporting bone was greater in premolar and molar regions compared to zirconia. This study demonstrates that using different material for fabrication of implant supported bridges directly affects the stress distribution in the peripheral bone which can enhance the knowledge in clinics to improve longevity of prosthesis.

Key Words: Dental Biomechanics, Zirconia, Trinia, Implant Length, Finite Element Modeling

1. Introduction

Implant dentistry has emerged as a fully accepted discipline in dentistry in the last few decades. Its concepts and treatment modalities have undergone tremendous changes during this period of development (Wahengbam et al, 2021). The successful replacement of lost natural teeth by osseointegrated implants has been a major advance in dentistry. To maximize the chance for long-term implant stability and function, years of clinical experience have fostered a consensus regarding many of the placement criteria and techniques (Tarnow et al, 1997). The scope of clinical dentistry has greatly broadened due to the use of dental implants for the oral rehabilitation of fully and partially edentulous patients, establishing additional treatment options in complex cases in which functional rehabilitation was formerly limited or inadequate. The predictability and long term success of dental implants have been well established, both in removable and fixed prostheses (Buser et al, 1994).

With the dental implant, the patient can eat more properly and the troublesomeness at times of embarrassment caused by removable partial and full dentures can be eliminated. Additionally, the implant is able to protect the remaining natural teeth, stop bone loss and restore facial skeletal structure (Van Staden et al, 2006). Dental implants have the goal of transferring bite loads to the bone and the surrounding tissues and they have become a common practice in dentistry (El Moheb et al, 2019).

Received: August 7, 2022
Accepted: January 2, 2023
Martani, N.S., & Hadi, B.N. (2023). Investigating The Effect of Trinia and Zirconia Implant Supported Fixed Partial Denture On Stress Distribution in Peripheral Bone: A Three Dimensional Finite Element Modeling. *Eurasian Journal of Science and Engineering*, *9*(1),252-261.

Thus, dental implants must be designed to distribute loads to the surrounding tissue in an augmented way. Cortical and cancellous bone are the two types of bone that can be distinguished, both in the mandible and maxilla. Both cortical and cancellous bone are anisotropic materials, and the difference between them is that trabecular bone is a compact bone and cancellous is a highly porous mineralized tissue surrounded in cortical bone (Schwiedrzik et al, 2013).

Several factors are used to influence load transfer from dental implants to bone such as the material, the magnitude and angulation of the load, the design of dental implant (mainly, length and diameter) or the quantity and quality of the surrounding bone (Prados-Privado et al, 2017). Zirconia is widely used to build prosthetic devices because of its good chemical properties, dimensional stability, high mechanical strength, toughness, and a Young's modulus (210 GPa) similar to that of stainless steel alloy (193 GPa). The mechanical properties of zirconia are the highest ever reported for any dental ceramic. The high initial strength and fracture toughness of zirconia results from a physical property of partially stabilized zirconia known as transformation toughening. (Piconi and Maccauro, 1999) In vitro studies of zirconium dioxide specimens demonstrate a flexural strength of 900- 1200 MPa and a fracture toughness of 9 to 10 MPa/m^2 (Anusavice et al, 2012). On the other hand, its ability to transmit light and its white color, similar to the color of natural teeth, makes it useful in esthetic restorations of the oral cavity (Ahmad, 1998).

As newer materials are being introduced in implant dentistry, it is important to acquire knowledge about the variety of materials available and understand the factors, which will contribute to the success or failure of the restorations. To weigh the advantages and disadvantages of various materials before proceeding with the treatment would be invaluable towards making a prudent decision in rendering the appropriate restoration to the patient in terms of optimal health, esthetics and function (Jiang et al, 2020). TRINIA™ CAD/CAM discs and blocks are composed of multidirectional interlacings of fiberglass and resin in several layers. In addition to the advantage of being lightweight, TRINIA™ has great flexural strength and a flexural modulus of elasticity similar to dentin (Ewers et al, 2018). The flexural strength is determined by means of the loading device in the classical three-point bending test. The tested material—in this case TRINIA™—bends under load. As long as the material does not deform under load, i. e. returns to its original form when the force declines, it remains within the elastic range. The material deforms (plastic range) and breaks in the end if the acting force exceeds the load limit. The range when that happens to TRINIA™ is similar to that of dentin. In other words: The flexural modulus of elasticity of TRINIA™ is 18.8GPa, compared to that of dentin being 12–14GPa and of titanium being 102–118 GPa.

The finite element (FE) analysis is an impending and important research implementation for biomechanical analyses in biological research. For modeling complex structures and analyzing their mechanical properties, finite element analysis is an ultimate method. For studying the biomechanics and the influence of mechanical forces on the biological systems FE modeling technique has now become widely accepted as a non-invasive and excellent tool. Visualization of superimposed structures, and the stipulation of the material properties of anatomic craniofacial structures are enabled by finite element analysis (Saxena and Chandak, 2016). It also allows to establish the location, magnitude, and direction of an applied force, as it may similarly assign stress points that can be theoretically measured. (Gao et al, 2006) Additional to these, it is easily repeatable as it does not affect the physical properties of the analyzed materials (Gao et al, 2006 and Viceconti et al, 2007).

To enhance the understanding regarding the influence of the material properties of the implant supported fixed partial denture on stress distribution in peripheral bone, the objective of this study was to analyze the effect of a newly developed material (Trinia) and the conventional Zirconia implant-supported fixed partial dentures on stress transformation and distribution in the surrounding bone of dental implants using validated FE modeling technique.

2. Materials and Methods

A lower left quadrant of a dentoform arch (dental model, KSD, Zhejiang, China "Mainland") was prepared for this study. The 4.5 mm in diameter and 11 mm in length implants (4.5mm Integra-CP™; Bicon dental implant, Boston, USA) were placed at the 35 and 37 area. A zero degree angle universal abutment (Universal Abutment System; Bicon dental implant, Boston, USA) was attached to each implant. A digital impression using TRIOS scanner (3Shape TRIOS® 3, Copenhagen, Denmark) was acquired and a frame for three-unit bridge with subsequent veneering materials was designed using 3shape dental system (3Shape dental system, Copenhagen, Denmark)) to extract an exact geometry for further simulations (Figure 1). To finalize the geometrical models which can be used in FE analyses, the digital data files were imported to Solidworks (Dassault Système©, Vélizy-Villacoublay, France) and the surfaces were trimmed and smoothed to achieve acceptable geometries for exporting to FE package (Figure 1).

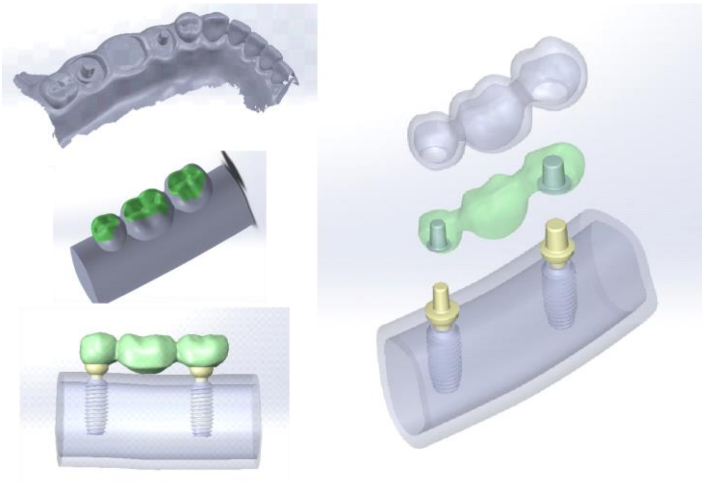

Figure 1: The geometrical model of the implant supported fixed partial denture

The bone structure that represented the lower left mandible at the region of premolars and molars were further modeled by using FE software (i.e., ABAQUS, SIMULIA, Providence, RI, USA) (Figure 2). 10-node quadratic tetrahedron elements were used to generate the meshed model, and sensitivity analyses to assess the independency of the results from meshing were performed. The number of elements and nodes for the FE model were 210893 and 327153, respectively (Figure 2).

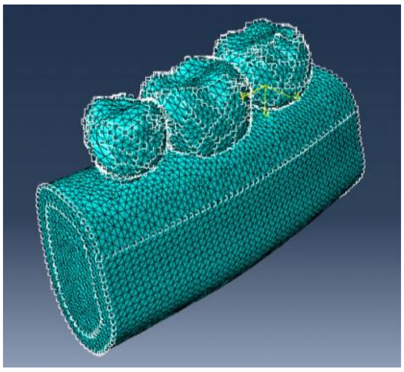

Figure 2. The developed finite element model of the implant supported fixed partial denture

Two different restorative materials Trinia (TRINIA®, Bicon dental implant, Boston, USA) and Zirconia (InCorisTZI; Sirona Dental System) were tested in terms of stress distribution. Mechanical properties of the model were considered as isotropic elastic theory, which was extracted from the available data in literature (Table 1) (Kitamura et al. 2004).

Table 1. Mechanical properties of different components in FE model (Kitamura et al. 2004)

Components	Elastic modulus (GPa)	Poisson's ratio
Implant (Titanium)	110	0.3
Zirconia	210	0.33
Trinia	18.5	0.3
Cancellous Bone	1.37	0.3
Cortical Bone	12.6	0.3

The analyses were classified as static and the solution examined the governing equation system using the element diagonal mass matrix and the law of explicit integration. The applied boundary condition between different components were considered using the discretization method of surface to surface with tie contact property to simulate perfect connection to constrain equal degrees of freedom (i.e., equal translational and rotational motions). The static compressive load equal to 150 N was vertically applied on the upper surface of the bridge for comparative analysis. The stress distribution in the surrounding bone were evaluated by using Von Mises stress criteria.

The calculated results of the Von-Mises stress from different simulations were extracted and the average and standard deviations for each component in each model were calculated. In addition, the achieved results were compared among two different materials using one-way ANOVA tests using SPSS package (SPSS Inc., Chicago, IL, USA). The statistical differences were considered to be significant at a p-value < 0.05.

3. Results

The results of Von Mises stress analysis for cortical bone surrounding implants are presented in Table 2. The occlusal force subjected to Trina bridge resulted in high stress in cortical bone in both supportive implants compared to zirconia bridge.

Table 2. Von-Mises stress analysis for cortical bone surrounding implants

Cortical Bone				
	Trinia-Composite		Zirconia-Ceramic	
	Premolar (MPa)	Moral (MPa)	Premolar (MPa)	Moral (MPa)
	18.05	56.40	11.76	32.55
	24.44	47.59	17.80	29.73
	30.70	37.09	24.09	26.54
	33.82	27.00	26.60	22.43
	34.07	26.76	25.98	21.79
	39.28	25.70	28.10	17.62
	47.52	39.23	31.93	23.42
	51.92	47.14	33.71	26.57
	48.31	46.27	30.39	28.43
	35.86	46.29	22.29	28.13
	27.34	49.74	19.51	29.22
	18.58	53.28	17.29	29.67
Mean	34.16	41.87	24.12	26.34
Standard Deviation	11.19	10.63	6.62	4.24

Comparing the result as shown in figure 3 indicated statistically significant differences were noticed between different restorative materials (Trinia and Zirconia) and while significant differences were found only in different regions of implant placement (Premolar and molar area) with Trinia but not with zirconia bridge in relation to stress distribution.

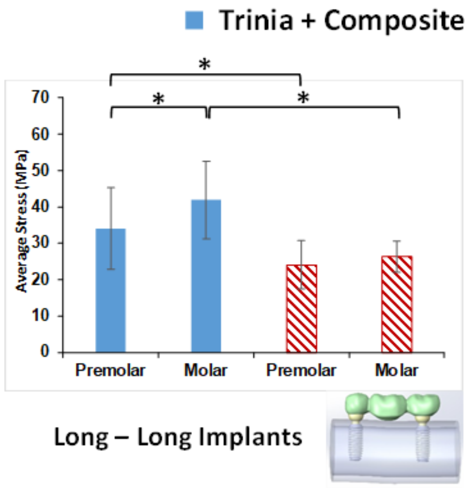

Figure 3: Comparative results for values of Von-Mises stress in cortical bone for different materials. The error bars indicate the standard deviations and "*" shows that p-values < 0.05.

The results of Von Mises stress analysis for cancellous bone surrounding implants are presented in Table 3 The occlusal force subjected to Trina and Zirconia bridges resulted in high stress in cancellous bone in both supportive implants.

Table 3: Von-Mises stress analysis for cancellous bone surrounding implants

Cancellous Bone				
	Trinia-Composite		Zirconia-Ceramic	
	Premolar (MPa)	Moral (MPa)	Premolar (MPa)	Moral (MPa)
	5.47	2.83	4.45	2.14
	4.93	9.70	4.02	7.63
	4.77	8.91	3.86	6.98
	3.86	6.45	3.09	5.10
	4.05	3.30	3.26	2.60
	3.82	7.45	3.09	5.90
	2.77	3.52	2.21	2.77
	3.77	8.22	3.01	6.47

	3.96	9.57	3.16	7.58
	4.37	8.99	3.50	7.14
	6.61	8.74	5.28	6.92
	4.39	12.02	3.50	9.55
Mean	4.40	7.47	3.54	5.90
Standard Deviation	0.97	2.90	0.79	2.31

Comparing the Von Mises stress in cancellous bone between the premolar and molar of 11mm in length and 4.5mm dental implants of the anatomical bridge of Trinia are and zirconia which were significant in both bridges of trina and zirconia as well as in in both implant regions as shown in figure 4.

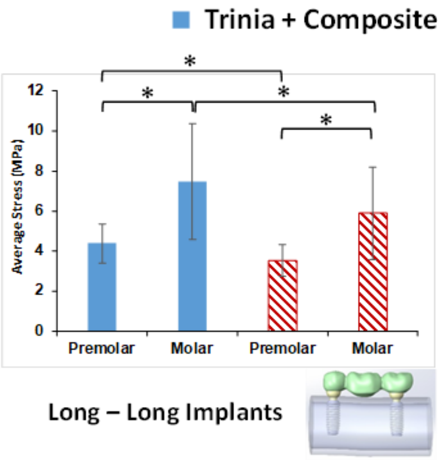

Figure 4: Comparative results for values of Von-Mises stress in cancellous bone for different materials. The error bars indicate the standard deviations and "*" shows that p-values < 0.05.

4. Discussion

A key factor for the success or failure of a dental implant is the manner in which stresses are transferred to the surrounding bone (Van Oosterwyck et al, 1998). The FE modeling as an in-silico investigation allows researchers to predict stress distribution in the contact area of implants with cortical bone and around the apex of implants in trabecular bone. The result of the present study revealed that two different restorative materials used in this study had significant effect on stress distribution in cortical and cancellous surrounding bones, therefore the hypotheses of using fiberglass reinforced to reduce stress distribution in surrounding bone was rejected.

Implants and natural teeth respond differently to masticatory forces and these differences are related to the existence or absence of periodontal ligaments, which serve as an elastic buffer. Analyzing the biomechanical responses of these structures is challenging because of the complexity of biomaterials, dental anatomy, and microstructural details (Anitua et al 2021a and 2021b). The FEA, which standardizes the parameters, is a suitable and analytic method of evaluating biomechanical behaviors in complex geometries. Moreover, a FE model can be 2D or 3D. In 2D models, out-of-plane deformations, strains, and stresses are insignificant, and artificial constraints result in more errors in the analysis. Therefore, the use of 3D models to analyze biological or biocompatible structures produces more realistic results than 2D models.

The von misses stress in cancellous bone between the premolar and molar of 11mm in length and 4.5mm dental implants of the anatomical bridge of Trinia were 4.4 to 4.7 for premolar and molar teeth. Hence, the differences of these values were significant in the premolars and molars of the anatomical bridges of trinia and zirconia. The premolar and molar of the anatomical bridge of zirconia where the least stress is at the premolar of zirconia-ceramic of the premolar (3.53) and the highest at the Trinia of the molar (7.47). This indicates that more stress will be induced in the cancellous bone (Miyamoto et al, 2005) in its results suggests that the initial stability at the time of implant installation is influenced more by cortical bone thickness than by implant dimensions. The cortical and cancellous ratio of local bone is extremely important for implant stability at the time of surgery and determining the local bone condition is critical for treatment success. Also, the results agree with reports of in vivo experiments that the amount of cancellous bone did not increase implant stability at the time of surgery (Nedir et al, 2004 and Sennerby et al, 1992). Opposing these findings (Anitua et al, 2021a) stated that implant dimensions have an important effect on bone stress, with a reduction in stress as the implant diameter increases.

Certain limitations in the current work should be reported. The first one is related to using isotropic elastic materials for cortical and cancellous bone. To focus on the main objective of this study which is a comparative investigation and reduce the cost of calculation, this simplification was adopted which can be tolerated. The second limitation lies in applying static vertical loading to models and no cyclic loading was considered. Although this is a common simplification in related studies, a supplementary study can be coupled with the current FE methodology for our future work.

5. Conclusions

This study developed a valid finite element (FE) modeling technique to investigate the effect of bridge materials on stress distribution in the surrounding bones of the implant-supported fixed partial dentures. Within the limitations of this study, the results showed that Zirconia bridge decreases the stress distribution in cortical and cancellous bone in comparison to Trinia three-unit bridge.

6. Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Ahmad I (1998). Yttrium-partially stabilized zirconium dioxide posts: an approach to restoring coronally compromised nonvital teeth. *International Journal of Periodontics & Restorative Dentistry*, 18.

Anitua E, Larrazabal Saez de Ibarra N, Morales Martín I & Saracho Rotaeche L (2021a). Influence of Dental Implant Diameter and Bone Quality on the Biomechanics of Single-Crown Restoration. *A Finite Element Analysis. Dentistry Journal*, 9, 103.

Anitua E, Larrazabal Saez de Ibarra N, Morales Martín I & Saracho Rotaeche LJDJ (2021b). Influence of Dental Implant Diameter and Bone Quality on the Biomechanics of Single-Crown Restoration. *A Finite Element Analysis*, 9, 103.

Anusavice KJ, Shen C & Rawls HR (2012). Phillips' science of dental materials, Elsevier Health Sciences.

Bahat O (2000). Brånemark system implants in the posterior maxilla: clinical study of 660 implants followed for 5 to 12 years. *International Journal of Oral & Maxillofacial Implants*, 15.

Benetti P, Kelly JR & Della Bona A (2013). Analysis of thermal distributions in veneered zirconia and metal restorations during firing. *Dental Materials*, 29, 1166-1172.

Buser D, Weber HP, Brägger U & Balsiger C (1994). Tissue integration of one-stage implants: three-year results of a prospective longitudinal study with hollow cylinder and hollow screw implants. *QUINTESSENCE INTERNATIONAL-ENGLISH EDITION*, 25, 679-679.

El Moheb M, Cherine F, Sghaireen M, Pati SR, Alam MK & Elie A (2019). Basal Implant: An Overview. *International Medical Journal*, 26.

Esposito M, Hirsch JM, Lekholm U & Thomsen P (1998). Biological factors contributing to failures of osseointegrated oral implants, (I). Success criteria and epidemiology. *European journal of oral sciences*, 106, 527-551.

Gao J, Xu W & Ding Z (2006). 3D finite element mesh generation of complicated tooth model based on CT slices. *Computer methods and programs in biomedicine*, 82, 97-105.

Gehrke SA, Frugis VL, Shibli JA, Fernandez MPR, de Val JEMS, Girardo JLC et al (2016). Influence of implant design (cylindrical and conical) in the load transfer surrounding long (13mm) and short (7mm) length implants: a photoelastic analysis. *The open dentistry journal*, 10, 522.

Jiang X, Yao Y, Tang W, Han D, Zhang L, Zhao K et al (2020). Design of dental implants at materials level: An overview. *Journal of Biomedical Materials Research Part A*, 108, 1634-1661.

Kelly JR & Benetti P (2011). Ceramic materials in dentistry: historical evolution and current practice. *Australian dental journal*, 56, 84-96.

Kitamura, E., Stegaroiu, R., Nomura, S., and Miyakawa, O. (2004). Biomechanical aspects of marginal bone resorption around osseointegrated implants: considerations based on a three-dimensional finite element analysis', *Clin Oral Implants Res*, 15(4), 401-412

Lekholm U (1985). Patient selection and preparation. Tissue-integrated prosthesis: osseointegration in clinical dentistry, 199-209.

Miyamoto I, Tsuboi Y, Wada E, Suwa H & Iizuka T (2005). Influence of cortical bone thickness and implant length on implant stability at the time of surgery—clinical, prospective, biomechanical, and imaging study. *Bone*, 37, 776-780.

Nedir R, Bischof M, Szmukler-Moncler S, Bernard JP & Samson J (2004). Predicting osseointegration by means of implant primary stability: A resonance-frequency analysis study with delayed and immediately loaded ITI SLA implants. *Clinical oral implants research*, 15, 520-528.

Piconi C & Maccauro G (1999). Zirconia as a ceramic biomaterial. Biomaterials; 20, 1-25.

Prados-Privado M, Bea JA, Rojo R, Gehrke SA, Calvo-Guirado JL & Prados-Frutos JC (2017). A new model to study fatigue in dental implants based on probabilistic finite elements and cumulative damage model. *Applied bionics and biomechanics*, 2017.

Prados-Privado M, Gehrke SA, Rojo R & Carlos Prados-Frutos J (2018). Probability of Failure of Internal Hexagon and Morse Taper Implants with Different Bone Levels: A Mechanical Test and Probabilistic Fatigue. *International Journal of Oral & Maxillofacial Implants*, 33.

Saxena A & Chandak M (2016). Finite Element Analysis (FEA) as a Decisive Tool for Study of Force Distribution in Dentistry. *Sch J Dent Sci*.

Schwiedrzik JJ, Wolfram U & Zysset PK (2013). A generalized anisotropic quadric yield criterion and its application to bone tissue at multiple length scales. *Biomechanics and modeling in mechanobiology*, 12, 1155-1168.

Sennerby L, Thomsen P & Ericson LE (1992). A morphometric and biomechanic comparison of titanium implants inserted in rabbit cortical and cancellous bone. *International Journal of Oral & Maxillofacial Implants*, 7.

Spiekermann H, Jansen VK & Richter E-J (1995). A 10-year follow-up study of IMZ and TPS implants in the edentulous mandible using bar-retained overdentures. *International Journal of Oral & Maxillofacial Implants*, 10.

Tarnow DP, Emtiaz S & Classi A (1997). Immediate loading of threaded implants at stage 1 surgery in edentulous arches: ten consecutive case reports with 1-to 5-year data. *International Journal of Oral & Maxillofacial Implants*, 12.

Trisi P & Rao W (1999). Bone classification: clinical-histomorphometric comparison. *Clinical oral implants research*, 10, 1-7.

Van Oosterwyck H, Duyck J, Vander Sloten J, Van der Perre G, De Coomans M, Lieven S et al (1998). The influence of bone mechanical properties and implant fixation upon bone loading around oral implants. *Clinical oral implants research*, 9, 407-418.

Van Staden R, Guan H & Loo Y-C (2006). Application of the finite element method in dental implant research. *Computer methods in biomechanics and biomedical engineering*, 9, 257-270.

Viceconti M, Zannoni C, Testi D, Petrone M, Perticoni S, Quadrani P et al (2007). The multimod application framework: a rapid application development tool for computer aided medicine. *Computer methods and programs in biomedicine*, 85, 138-151.

Wahengbam P, Fatima D, Sehrawat M, Budhiraja D & Ravi N (2021). A review on loading protocols in implants. *IP Annals of Prosthodontics and Restorative Dentistry*, 7, 37-40.