First Libyan International Conference on Engineering Sciences & Applications (FLICESA_LA)
13 – 15 March 2023, Tripoli – Libya

Numerical Study of Resilient Implant with micro-movable element Implemented in Dental Prosthesis

Amel A. al-zuweedi
Libyan Academy for Postgraduate Studies, Biomechanical Division, Tripoli.
Email Address:
Amel.alzuweedi@academy.edu.ly

Prof. Dr. Hussam El-Din F. El-Sheikh
Libyan Academy for Postgraduate Studies, Biomechanical Division, Tripoli.

Abstract—The aim of this study was to investigate the biomechanical behavior of resilient implant designs. The research presents a three-dimensional finite element analysis for tooth - implant supported prosthesis models which was designed with resilient implant with micro-movable element. To make the study more qualitative, invented design has been compared with the tooth-support fixed partial denture model. The tooth-implant supported dental prosthesis with the resilient implant with micro-movable element shows a high increase in maximum von Mises stress, which was 3899.7 MPa in the non-rigid connector. The stress distribution in the bone around the premolar was extremely high. Finally, it concluded that the resilient implant with a vertical micro-movable design has disappointingly affected the stress distribution in bone.

Keywords— finite element analysis, resilient implant, vertical micro-movable.

I. INTRODUCTION

A variety of prosthetic techniques can be used to restore the dentition subsequent to loss of teeth. The process of rehabilitation depends on the number, arrangement, and condition of residual teeth, patient desires, cost, and sufficiency of the bone to support dental implants [1].

Multiple missing teeth may possibly be restored with a removable partial denture, with a tooth-supported fixed bridge, with an implant-supported fixed bridge, or with a combined tooth-implant-supported bridge [2].

A combined tooth-implant-supported bridge, has been proven as an efficient modality of treatment, since the implant is connected to remaining natural teeth whenever there is an anatomic limitation of space for implants or failure of an implant to osseointegrated [3].

Resiliency of dental implant component [4], cushioning effect of cement and/or rapper layer [5], and force deflection in superstructure [6,7] may play a significant rule to this phenomenon. Therefore, biomechanical effect of mismatching of mobility pattern between the natural teeth and implant remains controversial [4,8].

Several published studies tried to achieve tooth-like mobility and shock absorbance, but only in an axial direction. Their solution consists of a vertical shock-absorbing mechanism in the abutment of the implant [9]. All of them obtained good results, but the periodontal system is a 3D structure which allows the tooth to move in all spatial directions, not just vertically. From the shock-absorbing point of view, in a vertical direction, most forces will be transmitted to the apex of the implant and to the apical portion thread [10]. Other studies suggest using 3D shock absorption enables the resulting forces to be transmitted in a more physiological manner to the surrounding bone [5].

The aim of this study was to investigate the biomechanical behavior of resilient implant with micro-movable element that form the integral part of tooth-implant fixed prostheses.

II. MATERIALS AND METHODS

A. The Design of the Implant System with micro-movable element design

This design was prepared with a component has the capability for vertical micro-movable to sustain the masticatory load. Therefore, a spring element was introduced underneath the abutment component to provide masticatory load absorption and also uniform stress distribution in the bone tissue around the implant. Some previous works have suggested the idea of imitating the natural teeth by using spring as a micro-movable element [9,11,12], Figures 1.

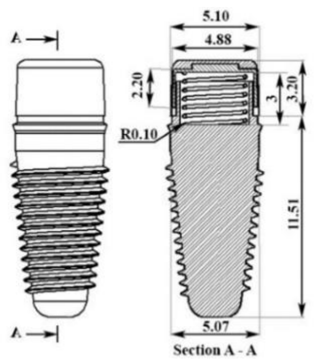

Figure 1: Side and sectional views and main dimensions of Resilient Implant with micro-movable element.

The elastic abutment with a mechanical behavior similar to a natural tooth with periodontal ligament has wide research and a commercially available product [9,10]. When there is a virtual load in occlusion surface, the abutment moves toward the implant, causing an increase in the compression of the resilient component, and reduce the over mechanical load. Nitinol was suggested as the material for the resilient component because it has the ability to restore the original shape after deformation [13,14]. Nitinol is used to manufacture medical devices due to its unique properties, such as biocompatibility, super elasticity, and fatigue resistance [15].

B. Finite Element Analysis of the Implant System

The research presents a three-dimensional finite element analysis for tooth - implant supported prosthesis models which was designed with resilient implant with micro-movable element. To make the study more qualitative, invented design has been compared with the tooth-support fixed partial denture model. The simulated models included the first premolar, first molar, cortical bone, calculus bone, periodontal ligament with a 0.2 mm thickness, dental implant, and the Zirconia dental prosthesis with non-rigid connectors.

The two undertaken models were first designed using SolidWorks_17, computer aid design software, then they have been exported to ANSYS_16 Workbench software for further mechanical analysis. The four models were manipulated as following:

- The tooth-supported dental prosthesis model, Figure 2.
- The tooth-implant supported dental prosthesis with resilient implant with micro-movable element model, figure 3.

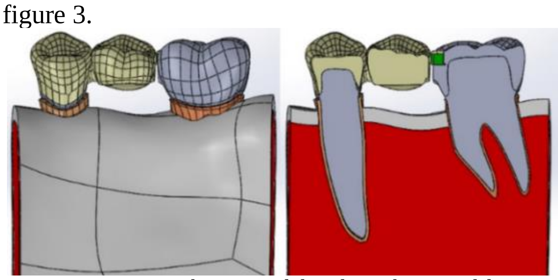

Figure 2: Tooth supported dental prosthesis model.

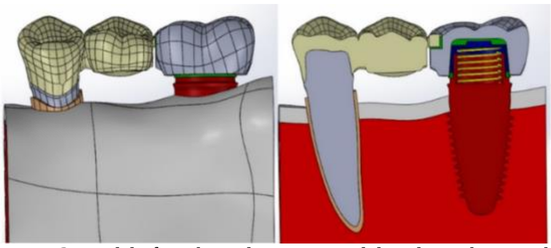

Figure 3: Model of tooth-implant supported dental prosthesis with resilient implant with micro-movable element.

This assembled component was then manipulated by meshing generation with element sizes of 0.5 mm at a Global Level, Figures 4-5. The number of elements and nodes of the models were described in Table 1.

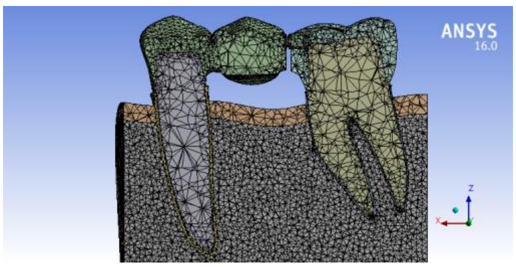

Figure 4: The meshes generated on the tooth supported dental prosthesis model.

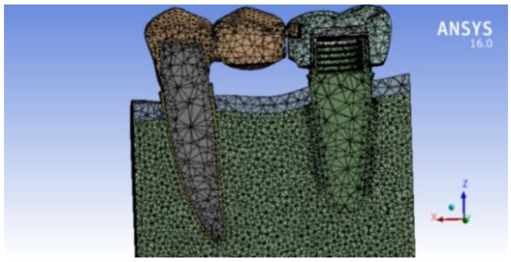

Figure 5: The meshes generated on the tooth-implant supported dental prosthesis with resilient implant with micro-movable element model.

Table 1: Number of elements and nodes in the finite element Models.

Models	Element	Nodes
tooth-supported prosthesis	405532	598108
tooth-implant supported prosthesis with resilient implant	456685	684735

Biological tissues is an anisotropic and heterogeneous material which means that they have different mechanical properties for loading in different directions [16,17]. The material properties used for the current models were assumed to be linear, homogeneous, and isotropic, Table 2.

Table 2: Mechanical properties of the materials used in the study.

Materials	Young's modulus (MPa)	Passion's ratio
Cortical bone [18,19]	15,000	0.3
Cancellous bone [18,19]	1,500	0.3
Periodontal ligament (PDL) [20]	69	0.45
Dentin [21]	18,600	0.31
Titanium [18,22]	110,000	0.35
Zirconia [20,23]	210,000	0.27
Nitinol [15]	28,000	0.3
Nonrigid connector [24]	110,000	0.42

This study has considered two different cases of force occlusion represented in two different simulations. In one simulation the applied force was considered vertical, while in the second simulation the semi-values of these forces were re-applied to the occlusal surface from buccolingual directions with inclination of 30° to the vertical axis of the prosthesis [25].

The direction characterization of the applied forces was illustrated in on figure, Figure 6, in which along the z-axis the applied forces were as fellow; 450 N was applied on the top surface of the first premolar, 600 N was on the top surface of the second premolar, and 720 N was applied on the top surface of the first molar.

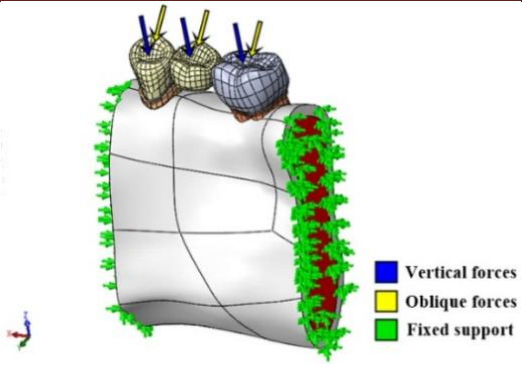

Figure 6: loads applied on the occlusal surface.

The boundary conditions in most FEA simulations of the mandible are fixed [26]. The tooth-supported dental prosthesis model is a sectional part of the alveolar, so the side faces of the mandible model are assumed to be fixed in all directions.

III. Results

The study evaluates under vertical and oblique loading the von Mises stresses generated in the bone around the tooth and considered the deformation as an indication for tooth displacement. The von Mises analysis was applied in the study to record the stress distribution in the mesial and distal sides of the tooth, based on a color expression that presents the results in the form of a chromatic scale, with the colors ranging from blue to red for the minimum values to the maximum values. Below are the analysis results:

A. *Tooth supported dental prosthesis model*

Under vertical loading, the maximum equivalent von Mises stress was about 3795 MPa in the prostheses, particularly in the nonrigid connector. The stress distribution in the bone around the roots was uniform with similar values, in the mesial side of the neck area the stress around the molar and premolar was 10.4 MPa and 10.9 MPa, respectively, while in the apex area the stresses decrease. On the distal side, the stress generated in bone around the molar and the premolar was 6.3 MPa and 6.7 MPa, respectively. However, the stresses increase gradually all the way down in the tip of the root area, Figure 7.

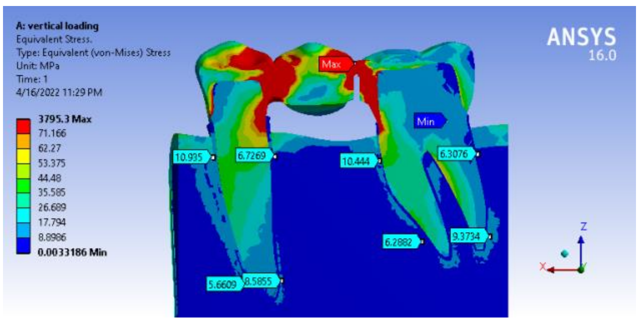

Figure 7: The von Mises stress under vertical load applied on Tooth supported dental prosthesis model.

Under oblique loading, the von Mises stresses elevated to the maximum value up to 3846 MPa at nonrigid connector. The stresses around the molar tooth were 9 MPa on the mesial side and almost 7 MPa on the distal side, whereas in the premolar tooth they were higher of about 13.2 MPa in the mesial and 8.3 MPa in the distal, as shown in Figure 8.

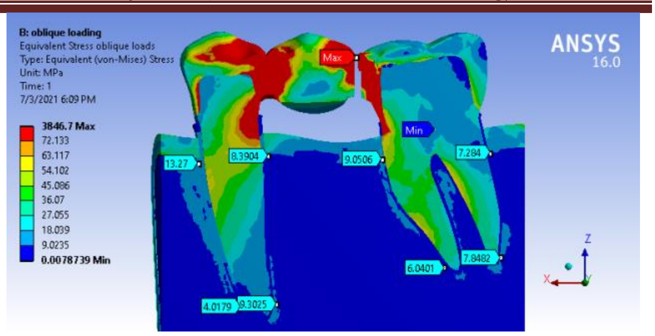

Figure 8: The von Mises stress under oblique load applied on Tooth supported dental prosthesis model.

Under vertical loads the maximum displacement of whole prosthesis reached to 108 µm Figure 9. It was noticed that the amount of micro-displacement in the anterior teeth was higher than that of posterior's, hence the premolar displacement was 103 µm and that of the molar was 90 µm.

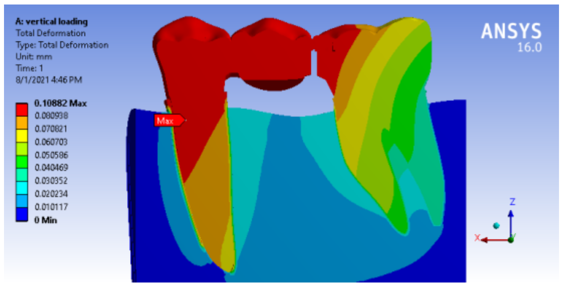

Figure 9: The displacement under vertical load applied on tooth supported dental prosthesis model.

While under oblique loads the maximum value of displacement of whole prosthesis was increased up to 175 µm Figure 10. The displacement in the molar was 139 µm since the occlusal applied once was higher, whereas in the premolar was record to be 131 µm.

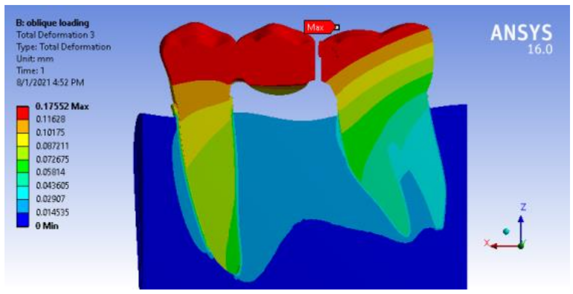

Figure 10: The displacement under oblique load applied on Tooth supported dental prosthesis model.

B. *Tooth-implant supported dental prosthesis with resilient implant with micro-movable element model.*

Under vertical loading, this model shows a high increase in maximum von Mises stress, which was 3899.7 MPa in the nonrigid connector. The stress distribution in the bone around the premolar was extremely high, and the stresses in the mesial and distal sides were 11 MPa and 8 MPa, respectively. While near the implant, it shows significant stress absorption on the mesial side, which decreases to 2 MPa and then rise up to 12 MPa on the distal side, Figure 11.

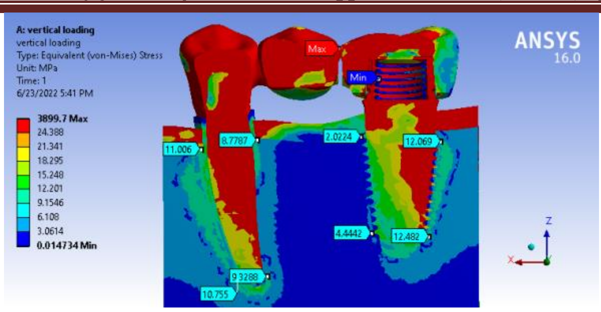

Figure 12: The von Mises stress under vertical load applied on tooth-implant supported dental prosthesis with resilient implant with micro-movable element model.

Under oblique loading, the von Mises stresses are elevated to their maximum value up to 7448 MPa at nonrigid connector. The stresses around the implant were 2 MPa on the mesial side and almost 13 MPa on the distal side, whereas in the premolar tooth they were extremely high of about 15 MPa in the mesial and 10 MPa in the distal, as shown in Figure 12.

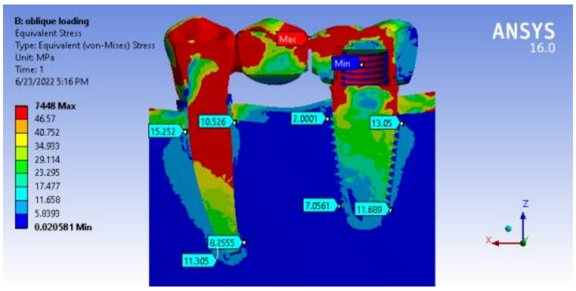

Figure 12: The von Mises stress under oblique load applied on tooth-implant supported dental prosthesis with resilient implant with micro-movable element model.

The results of this model were the highest, since the maximum total displacement of the whole prosthesis reached to 248 µm under vertical loads, Figure 13. The implant displacement was 20 µm, while the displacement of the implant micro-movable element was 240 µm, which caused rise in the premolar displacement up to 151 µm.

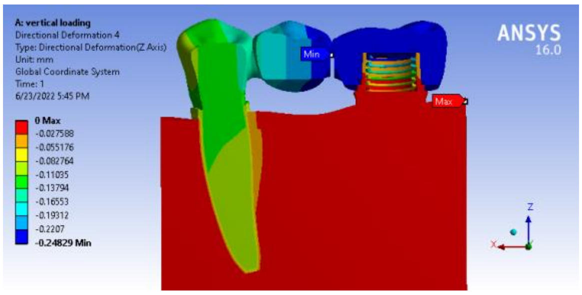

Figure 14: The displacement under vertical load applied on tooth-implant supported dental prosthesis with resilient implant with micro-movable element model.

While under oblique loads the maximum value of displacement was increased up to 257 µm, Figure 15. The displacement in the implant micro-movable element was 255 µm. Whereas in the premolar was record to be 149 µm,.

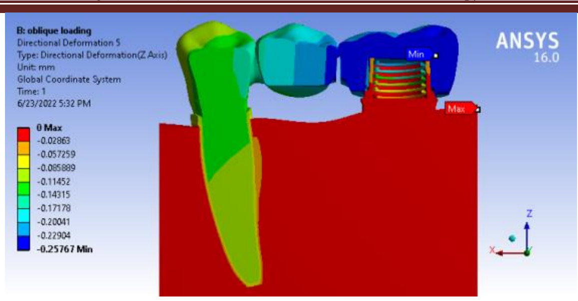

Figure 15: The displacement under oblique load applied on tooth-implant supported dental prosthesis with resilient implant with micro-movable element model.

IV. DISCUSSION

In mechanical systems, soft materials are commonly used as shock absorber devices to dampen force transfer between rigid components [12]. In the same way, a viscoelastic periodontal ligament subsists in the natural tooth-bone system serves to dampen the masticatory stresses towards the bone [27–29]. Likewise, in a resilient dental implant, when a shock absorber component shows elastic behaviour, which is inserted between stiff components of the implant, can reduce the load transfer towards the surrounding bone [10,30].

Many researchers studied the use of teeth and implants to support fixed partial dentures, but the effects are still controversial. Besides the advantages, there are potential consequences due to the biomechanical difference such as tooth intrusion and bone loss [3,31]. The effect of a resilient dental implant as a splint on the natural abutment has been discussed in several studies [5,8,32]. Most reported that using this kind of implant with resilient components has reduced the stress values in the bone tissue around the tooth and implant [9,10,33].

In the present study, design of resilient implants with micro-movable element was compared with a natural tooth to evaluate the ability of implants to mimic the movement of PDL based on the stress criteria by using finite element approach. The implant was combined with a tooth in a fixed partial denture by a non-rigid connector. Vertical and oblique loads were applied to the occlusal surface of the prosthesis with the highest values of biting force to evaluate the mechanical behavior of the implant under extreme conditions.

In tooth-supported dental prosthesis model, the stresses in the bone around the teeth were almost the same under the vertical loads. The stress on the mesial side was higher and decreased all the way down to the apex of the root, whereas on the distal side the stresses were higher in the root apex area than in the neck area since the root apex was inclined distally, and the rotation center of the root was located in the apical third area [34]. Under oblique loads, the stress distribution pattern was similar to that under the vertical loading, in spite that its values were higher especially around the premolars. . The micro-displacement results due to vertical and oblique loading showed normal motility range similar to the natural teeth under occlusal load which is reported to be 200 µm under compression loading with speed of 10 µm/s [28].

The highest von Mises stress values has been recorded in tooth-implant supported dental prosthesis by resilient implant with micro-movable element model under both vertical and oblique loads, which they were 3899 MPa and 7448 MPa, respectively. Obviously, this would lead to damage of the prosthesis since the stress around the premolar was too high compared with other models, beside the stresses were low on the mesial side of the implant. That means resilient implant with micro-movable design which provide vertical displacement failed to transfer the stresses to the bone in an appropriate way. Consequently, this may result in bone atrophy due to stress shielding [35,36]. In addition, the cantilever effect played major role in creating bending moments owing to physiological tooth movement which in return could lead to prosthesis fracture, and implant failure. Furthermore, the resulted displacement under vertical and oblique loading were, also, too high. The mobility of the resilient abutment acts in a way effect on the premolar, leading to greater displacement values than the normal range, which would cause serious problems.

Mehran Ashrafi et al [37] made a comparative study of implant designs with and without absorbers to analyze the stress distributions in both bone and implant, as well as the relative micromovement of the implant, also presented the evolution of damage and bone volume fraction. The results showed that absorbers could reduce stresses in the bone surrounding the implant and thus bone damage could be minimized. In contrary, increasing the number of absorbers does not necessarily improve damage reduction.

The ability of resilient dental implants to reduce the overloading in tooth-implant prosthesis was recorded in several studies. Omer Pektasx and Ergin Tonuk [10] in their study designed a dental implant with resilient components in the upper structure to mimic the mechanical behaviour of the periodontal ligament in only the axial direction, the results of the designed implant were similar to a natural tooth with PDL and that is the purpose presented for eliminating or at least reducing the reported problems of rigid implants. Furthermore, when a bridge was co-supported by the elastic implant and a natural tooth, the maximum stress at the crown was reduced to 18%, at the abutment to 5%, and at the neck to 1% of the stresses found for the bridge co-supported by a generic rigid implant and a natural tooth. Nevertheless, the implant was designed for axial instead of horizontal flexibility. Consequently, the displacement under horizontal loading (1.3 mm) was extremely smaller than that reported on a natural tooth (50–150 mm). In the same context and from my point of view, since the geometries of both the bridge and the natural tooth were not professional, and the applied loads were just in a vertical direction the results were inaccurate, but one could consider this effort as a good base for resilient-implant design.

Another study by Mirko Glišić et al [9] used finite element method to analyze load distribution in tooth-implant supported fixed partial dentures with the use of resilient TSA (Titan Shock Absorber, Bone Care GmbH, Augsburg, Germany) abutment and standard non-resilient abutment. The experiment applied only a vertical force of 500 N in three different axial load conditions. The results showed maximum stress values were recorded in the cortical region of the bone in all three situations, for the model with a non-resilient abutment (maximum stress value of 49.7 MPa) and in the model with a resilient TSA abutment (maximum stress value of 28.9 MPa). The resilient TSA abutment results in a more uniform distribution of stress and deformations in the bone tissue. These results are much lower than in the model with the non-resilient abutment. The resilient abutment spring, which absorbs a portion of the force, prevents excessive load on the implant produced by tooth intrusion. According to the author, this study did not used oblique loads which are considered important to mimic the occlusal forces and could give realistic impacts and results.

V. CONCLUSION

Finally, the conclusion has been reached based on the present study results and observations that the resilient implant with a vertical micro-movable design has disappointingly affected the stress distribution in bone.

REFERENCES

[1] Pratheep K, Abraham A, Annapoorni H, Vigneshwaran S. Comparative evaluation of stresses in tooth implant connected fixed partial denture by varying the implant design and position: A 3D finite element study. Indian J Dent Res 2013;24:439–45. https://doi.org/10.4103/0970-9290.118388.

[2] Ramoglu S, Tasar S, Gunsoy S, Ozan O, Meric G. Tooth-Implant Connection: A Review. ISRN Biomater 2013;2013:921645. https://doi.org/10.5402/2013/921645.

[3] Shenoy V, Rodrigue S, Prashanti E, Saldanha S. Tooth implant supported Prosthesis: A Literature review. J Interdiscip Dent 2013;3:143–50. https://doi.org/10.4103/2229-5194.131198.

[4] Cho GC, Chee WW. Apparent intrusion of natural teeth under an implant-supported prosthesis: a clinical report. J Prosthet Dent 1992;68:3–5. https://doi.org/10.1016/0022-3913(92)90274-e.

[5] Manea A, Baciut G, Baciut M, Pop D, Comsa DS, Buiga O, et al. New Dental Implant with 3D Shock Absorbers and Tooth-Like Mobility-Prototype Development, Finite Element Analysis (FEA), and Mechanical Testing. Mater (Basel, Switzerland) 2019;12. https://doi.org/10.3390/ma12203444.

[6] Sullivan DY. Prosthetic considerations for the utilization of osseointegrated fixtures in the partially edentulous arch. Int J Oral Maxillofac Implants 1986;1:39–45.

[7] Finger IM, Guerra LR. Prosthetic considerations in reconstructive implantology. Dent Clin North Am 1986;30:69—83.

[8] Charkawi H, Zekry K, El-Wakad MT. Stress analysis of different osseointegrated implants supporting a distal extension prosthesis. J Prosthet Dent 1995;72:614–22. https://doi.org/10.1016/0022-3913(94)90294-1.

[9] Glišić M, Stamenković D, Grbović A, Todorović A, Marković A, Trifković B. Analysis of load distribution in tooth-implant supported fixed partial dentures by the use of resilient abutment. Srp Arh Celok Lek 2016;144:188–95. https://doi.org/10.2298/SARH1604188G.

[10] Pektaş Ö, Tönük E. Mechanical design, analysis, and laboratory testing of a dental implant with axial flexibility similar to natural tooth with periodontal ligament. Proc Inst Mech Eng Part H J Eng Med 2014;228:1117–25. https://doi.org/10.1177/0954411914557713.

[11] Chen YY, Chen WP, Chang HH, Huang SH, Linb CP. A novel dental implant abutment with micro-motion capability - Development and biomechanical evaluations. Dent Mater 2014;30:131–7. https://doi.org/10.1016/j.dental.2013.10.007.

[12] Mehdi G, Belarbi A, Mansouri B, Azari Z. Numerical study of effect of elastomeric stress absorbers on stress reduction in bone-dental implant interface. J Appl Oral Sci 2015;23:87–93. https://doi.org/10.1590/1678-775720140086.

[13] Kapoor D. Nitinol for Medical Applications: A Brief Introduction to the Properties and Processing of Nickel Titanium Shape Memory Alloys and their Use in Stents. Johnson Matthey Technol Rev 2017;61:66–76. https://doi.org/10.1595/205651317X694524.

[14] Philip GB, Jhamb M, George EMI, Jhamb R. Titanium and its role in Dentistry. Internatinal J Sci Res Publ 2017;7:602–8.

[15] Gusarov B. PVDF piezoelectric polymers : characterization and application to thermal energy harvesting 2015.

[16] Hu C, Qin Q-H. Bone remodeling and biological effects of

mechanical stimulus. AIMS Bioeng 2020;7:12–28. https://doi.org/10.3934/bioeng.2020002.

[17] Desai H MS. Basic Concepts of Finite Element Analysis and its Applications in Dentistry: An Overview. J Oral Hyg Heal 2014;02. https://doi.org/10.4172/2332-0702.1000156.

[18] Cicciù M, Cervino G, Bramanti E, Lauritano F, Gudice G Lo, Scappaticci L, et al. FEM analysis of mandibular prosthetic overdenture supported by dental implants: Evaluation of different retention methods. Comput Math Methods Med 2015;2015. https://doi.org/10.1155/2015/943839.

[19] Burak OZcelik T, Ersoy E, Yilmaz B. Biomechanical Evaluation of Tooth- and Implant-Supported Fixed Dental Prostheses with Various Nonrigid Connector Positions: A Finite Element Analysis. J Prosthodont 2011;20:16–28. https://doi.org/10.1111/j.1532-849X.2010.00654.x.

[20] Jain H, Kalra T, Kumar M, Bansal A, Jain D. Three-Dimensional Finite Element Analysis to Evaluate Stress Distribution in Tooth and Implant-Supported Fixed Partial Denture–An In Vitro Study. Dent J Adv Stud 2020;8:84–91. https://doi.org/10.1055/s-0040-1714331.

[21] de Paula GA, Silva GC, Vilaça ÊL, Cornacchia TM, de Magalhães CS, Moreira AN. Biomechanical behavior of tooth-implant supported prostheses with different implant connections: A nonlinear finite element analysis. Implant Dent 2018;27:294–302. https://doi.org/10.1097/ID.0000000000000737.

[22] Lin C-L, Wang J-C, Kuo Y-C. Numerical simulation on the biomechanical interactions of tooth/implant-supported system under various occlusal forces with rigid/non-rigid connections. J Biomech 2006;39:453–63. https://doi.org/10.1016/j.jbiomech.2004.12.020.

[23] Cervino G, Romeo U, Lauritano F, Bramanti E, Fiorillo L, D'Amico C, et al. Fem and Von Mises Analysis of OSSTEM ® Dental Implant Structural Components: Evaluation of Different Direction Dynamic Loads. Open Dent J 2018;12:219–29. https://doi.org/10.2174/1874210601812010219.

[24] Muradyan TA, Muradyan NA, Verlinski S V., Poghosyan AY. Three-dimensional finite element analysis comparative model of tooth–implant nonrigid fixation. Simulation 2021;97:239–46. https://doi.org/10.1177/0037549720972781.

[25] Dalkiz M, Zor M, Aykul H, Toparli M, Aksoy S. The Three-Dimensional Finite Element Analysis of Fixed Bridge Restoration Supported by the Combination of Teeth and Osseointegrated Implants. Implant Dent 2002;11:293–300. https://doi.org/10.1097/00008505-200207000-00016.

[26] In A, Use THE, Fea OF, Implant-bone THE. Application of finite element analysis in implant dentistry: A review of the literature. J Prosthet Dent 2001;85:585–98.

[27] Chang H-H, Yeh C-L, Wang Y-L, Huang Y-C, Tsai S-J, Li Y-T, et al. Differences in the biomechanical behaviors of natural teeth and dental implants. Dent Mater 2021. https://doi.org/https://doi.org/10.1016/j.dental.2021.01.003.

[28] Qian L, Todo M, Morita Y, Matsushita Y, Koyano K. Deformation analysis of the periodontium considering the viscoelasticity of the periodontal ligament. Dent Mater 2009;25:1285–92. https://doi.org/10.1016/j.dental.2009.03.014.

[29] Su MZ, Chang HH, Chiang YC, Cheng JH, Fuh LJ, Wang CY, et al. Modeling viscoelastic behavior of periodontal ligament with nonlinear finite element analysis. J Dent Sci 2013;8:121–8. https://doi.org/10.1016/j.jds.2013.01.001.

[30] Del Palomar AP, Arruga A, Cegoñino J, Doblaré M. A finite element comparison between the mechanical behaviour of rigid and resilient oral implants with respect to immediate loading. Comput Methods Biomech Biomed Engin 2005;8:45–57. https://doi.org/10.1080/10255840500141593.

[31] Al-Omiri MK, Al-Masri M, Alhijawi MM, Lynch E. Combined Implant and Tooth Support: An Up-to-Date Comprehensive Overview. Int J Dent 2017;2017:6024565. https://doi.org/10.1155/2017/6024565.

[32] Salazar, Alfred Guerra R. STRESS ABSORBING SEMIPERMANENT DENTAL IMPLANT SYSTEM 1993.

[33] van Rossen IP, Braak LH, de Putter C, de Groot K. Stress-absorbing elements in dental implants. J Prosthet Dent 1990;64:198–205. https://doi.org/10.1016/0022-3913(90)90179-G.

[34] Weinberg LA. The biomechanics of force distribution in implant-supported prostheses. Int J Oral Maxillofac Implants 1993;8:19–31.

[35] Misch CE. Dental Implant Prosthetics. J Maxillofac Oral Surg 2014:1–993.

[36] Brunski JB, Puleo DA, Nanci A. Biomaterials and biomechanics of oral and maxillofacial implants: current status and future developments. Int J Oral Maxillofac Implants 2000;15:15–46.

[37] Ashrafi M, Ghalichi F, Mirzakouchaki B, Arruga A, Doblare M. Finite element comparison of the effect of absorbers' design in the surrounding bone of dental implants. Int j Numer Method Biomed Eng 2020;36:0–1. https://doi.org/10.1002/cnm.3270.