The Open European Journal for Research in Medical and Basic Sciences (OEJRMBS)
ISSN: 3062-3464
Volume 2, Issue 2, 2026, Pages: 01-12
Journal homepage:
https://easdjournals.com/index.php/oejrmbs/index

Biomechanical Evaluation of Dental Prosthesis Using 3D Finite Element Analysis

Amel A. Al-Zuweedi [1*], Hussam El-Din F. El-Sheikh [2], Taha Muftah Abuali [3]
Amel.alzuweedi@academy.edu.ly ✉
[1] College of Medical Sciences and Technology, Tripoli, Libya
[2] Department of Biomedical Engineering, School of Engineering,Libyan Academy, Tripoli-Libya
[3] Department of Mechanical and Petroleum Engineering, Faculty of Technical Sciences, Bani Walid Libya.

Article history	Received 20 November 2025	Accepted 13 January 2026	Publishing 29 January 2026

ABSTRACT:

The aim of this paper was to study the micro-movement of a normal tooth and the dental implant that form the integral part of fixed dental prostheses. The research presents a three-dimensional finite element analysis for two different models, the tooth-implant fixed partial denture model and tooth-support fixed partial denture model. The simulated models included the first premolar, first molar, cortical bone, cancellous bone, periodontal ligament, dental implant, and the Zirconia dental prosthesis. Under loading, the natural tooth shows a higher movement rate than the dental implant. Based on the study result, it could be concluded that, despite the finite element analysis giving an approximate solution, the finite element simulations did provide a reasonable assessment and a good understanding of the support units' mechanical behavior.

Keywords:finite element analysis, simulation, micro-movement, normal tooth, dental implant

INTRODUCTION

Since the 1960s, Finite Element Analysis (FEA) has been commonly used in a variety of engineering and bioengineering fields through numerical analysis [1]. Finite element analysis (FEA) is purely a mathematical way to solving complex problems in the universe, since it allows for a more simplistic mathematical solution to biological problems. Many people are constantly confused by the words FEM and FEA. Both are, in fact, the same thing. In industry, FEA is more common, while FEM is more common at universities [2].

The use of computational methods and engineering knowledge in dentistry has benefited the understanding of oral biomechanics [1]. As, for predicting the deformation patterns and the effects of stress on the implant and its surrounding bone, finite element analysis (FEA) has become an increasingly useful method [3]. Also, the concept of stress analysis of dental structures has been a popular subject, to evaluate stresses of dental structures and improve their mechanical strength [4].

A natural tooth is attached to the alveolar bone via connective tissue known as periodontal ligament (PDL) [5], which displays elastic response followed by a viscoelastic phase when subjected to a continuous load [1]. The periodontal ligament (PDL) act as a shock absorber in a natural tooth, allows an apical intrusion of around 28 µm and lateral movement of about 50-108 µm[6].

A dental implant is a treatment for the rehabilitation of many functional, anatomical, or aesthetic problems due to tooth loss [7]. The implant is osseointegrated, which means artificial material fusion into the bone, so the implant cannot be separated from the bone without fracture [8,9], as result the implant exhibit only linear movement during loading cycle in proportion to the applied load without initial rapid movement due to lack of periodontal ligament [10]. Connecting teeth to implants led to a challenging biomechanical system that provides the prosthesis with different support, and thus stress, at both ends of the system [11].

The aim of this study was to investigate the micro-movement of a normal tooth and the dental implant at the tooth-implant fixed prostheses by finite element analysis.

FINITE ELEMENT MODEL VALIDATION

As a first step, it is important to validate the results of our model to grantee that the subsequent results are close to the reality. This process helps ensure that the model is accurate and can be used for dental research. As biomechanics models get more complicated and contain more components of the prosthetic system, it becomes more difficult to validate the model. However, the validation of FE models by using empirical studies is few and far between. Therefore, in our study we confined on numerical models quoted from certain papers. A finite element model was adjusted to correspond with previously published research to validate this study. The model was constructed of the tooth, alveolar bone (cortical and cancellous), zirconia crown, and periodontal ligament, Figure 1.

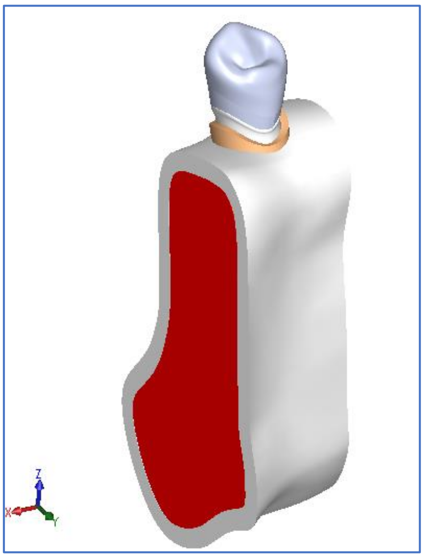

Figure 1: The model of single premolar.

The viscoelastic properties of the periodontal ligament play a significant role in the biomechanics of natural teeth and allow mobility to about 50–200 µm [12]. Jones et al.[13] validated a FEM model and discovered that the materials properties of periodontal ligament were difficult to quantify because periodontal ligament displayed an initial elastic response followed by a viscoelastic phase when subjected to a continuous load.

The force–displacement relationship of a tooth under an applied force is represented by a nonlinear curve. Assuming the linear elasticity of the periodontal ligament as a constant material property may result in a mistaken solution. The use of the linear static model is suitable only for expressing the displacement of a tooth under a specific range of applied load, and defining an elastic modulus of periodontal ligament [2].

Previous research has considered the periodontal ligament as a 0.25 mm thick layer around the tooth [14–18]. The elastic modulus and Poisson's ratio of the periodontal ligament was 2 MPa and 0.15, respectively [15,19].

The results of tooth displacement reported in several researches were used to validate this model. The data of this studies were gleaned from the living subjects such as the study presented by Száva et al. [20], to investigate the micro-movement pattern of the premolar tooth using the video image correlation method. As well as, a study by Parfitt et al. [21] that investigated the physiological mobility of upper incisor tooth in an axial direction. In addition, there is the experiment by Robinson et al. [22] which measures the mechanical response to loading at the occlusal surface of first mandibular premolar by using an extracted tooth. The same load conditions used in these mentioned research papers have been re-applied to the present models with two different mechanical properties of the periodontal ligament, Figure 2.

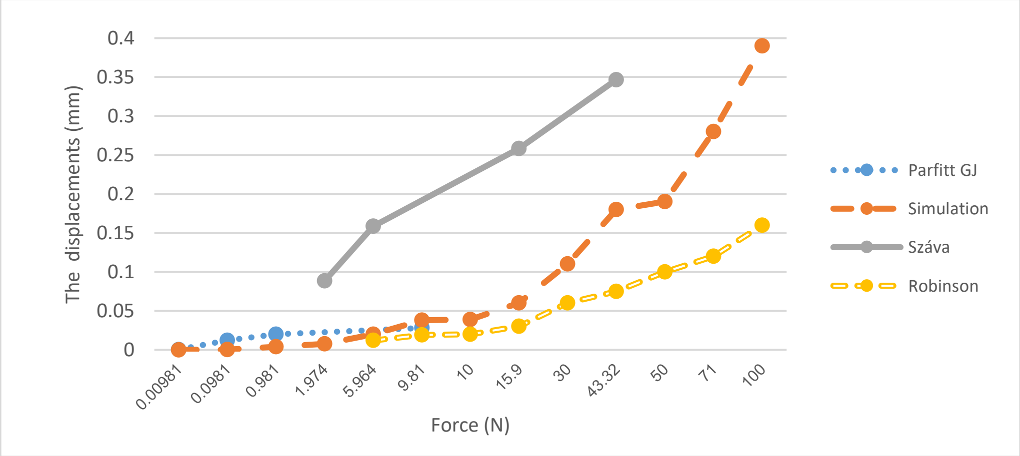

Figure 2: The force–displacement relationship of a tooth under applied force.

Among this comparison one could conclude that the present study is close the mentioned published studies and the deviation may be due to the difference in the geometry dimensions and material manipulation of the premolar model.

FINITE ELEMENT ANALYSIS OF THE DENTAL PROSTHESIS

The research presents a three-dimensional finite element analysis for tooth - implant supported prosthesis model designed to compare with the tooth-support fixed partial denture model. The simulated models included the first premolar, first molar, cortical bone, calculus bone, periodontal ligament, dental implant, and the Zirconia dental prosthesis with non-rigid connectors, Figures (3 - 4).

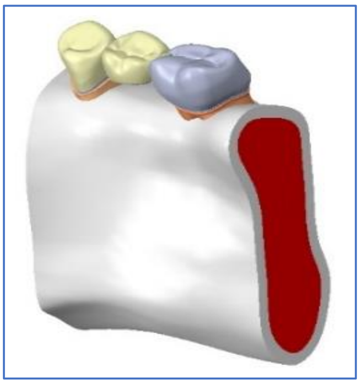

Figure 3: The model of tooth-support fixed partial denture.

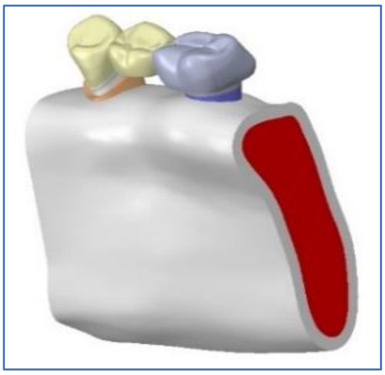

Figure 4: The model of tooth-implant supports fixed partial denture.

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 models were meshing generation with element sizes of 0.5mm at a Global Level, Figures 5-6. The number of elements and nodes of the models were described in Table 1.

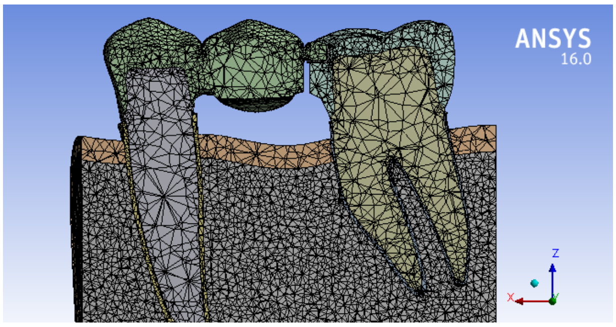

Figure 5: The meshes generated on the tooth supported dental prosthesis model.

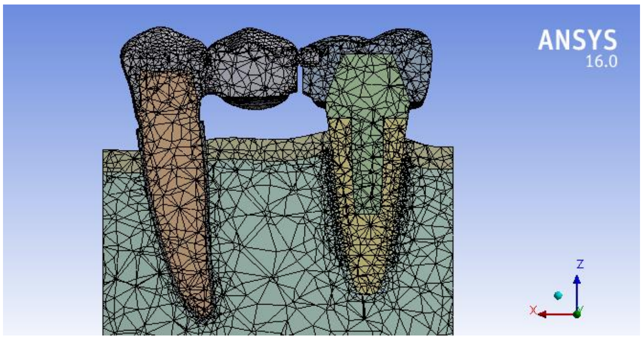

Figure 6: Meshes generation of tooth-implant supported prosthesis model.

Table 1: Number of elements and nodes in the study.

Models	Elements	Nodes
tooth supported dental prosthesis	405,532	598,108
tooth-implant supported prosthesis	99,831	174,605

Biological tissues is an anisotropic and heterogeneous material which means that they have different mechanical properties for loading in different directions [4,23]. The material properties used for the current model 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)	Poisson's ratio
Cortical bone [24,25]	15,000	0.3
Cancellous bone [24,25]	1,500	0.3
Dentin [26]	18,600	0.31
Zirconia [27,28]	210,000	0.27
Titanium [17,24]	110,000	0.35
Nonrigid connector [15]	110,000	0.42

LOADS AND BOUNDARY CONDITIONS

Axial loads of 100N were applied at the occlusal surface of the prosthesis to simulate regular biting force. Bonded contact concept was imposed on all the contact regions.

In this model a segment from mandible jaw was virtually taken off to be undergone the proposed simulation, and for this reason it was fixed in all directions, see Figure 7.

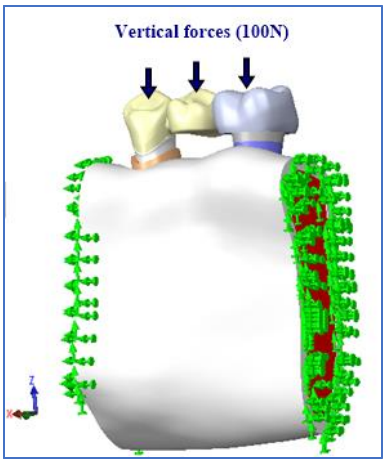

Figure 7: loads applied on the occlusal surface.

RESULTS

The study evaluates under vertical loading the displacement of the prosthesis and their supports units and considered the deformation as an indication for tooth displacement. After applying all boundary conditions and material properties, FEA models are solved by mechanical analysis with the help of Ansys Workbench16. Below are the analysis results:

Under vertical loads the maximum displacement of whole prosthesis reached to 149 µm Figure 8. 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 134 µm and that of the molar was 81 µm, Figures (9-10).

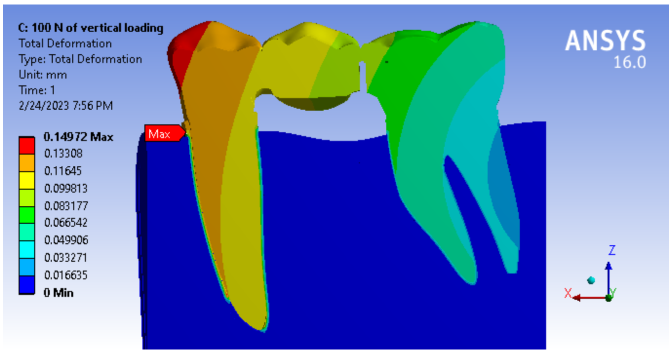

Figure 8: The displacement under oblique load applied on tooth supported dental prosthesis model.

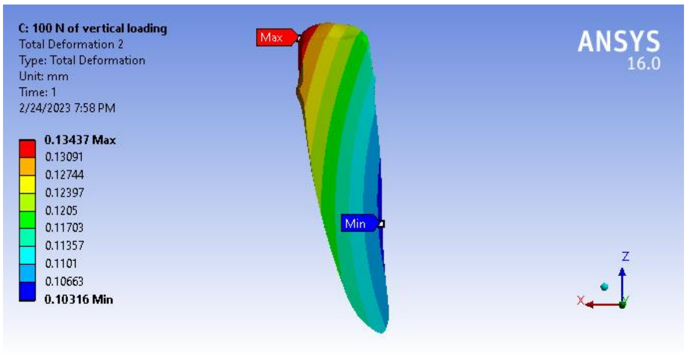

Figure 9: The displacement under oblique load applied on premolar in tooth supported dental prosthesis model.

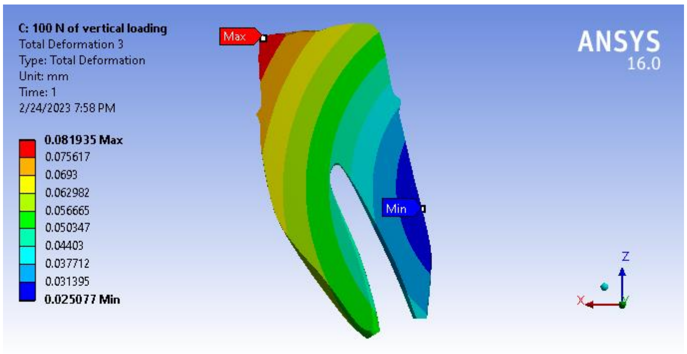

Figure 10: The displacement under oblique load applied on molar in tooth supported dental prosthesis model.

Under vertical loads, the maximum value of micro-displacement in the tooth-implant-supported dental prosthesis model was 70 µm, Figure 11. The premolar displacement was 65 µm, Figure 12. While the implant displacement was extremely low at 6 µm because the implant was rigidly fixed to the alveolar bone by osseointegration, Figure 13.

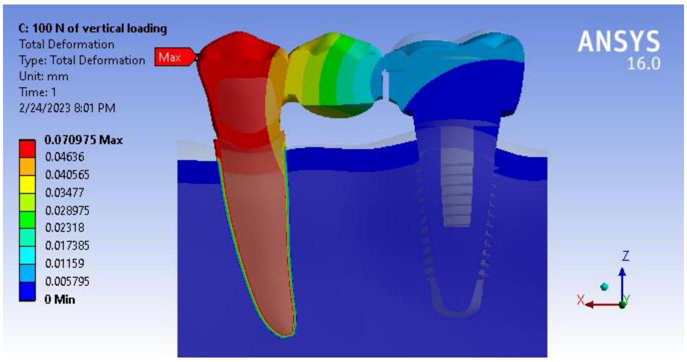

Figure 11: The displacement under vertical load applied on model of tooth-implant supported dental prosthesis

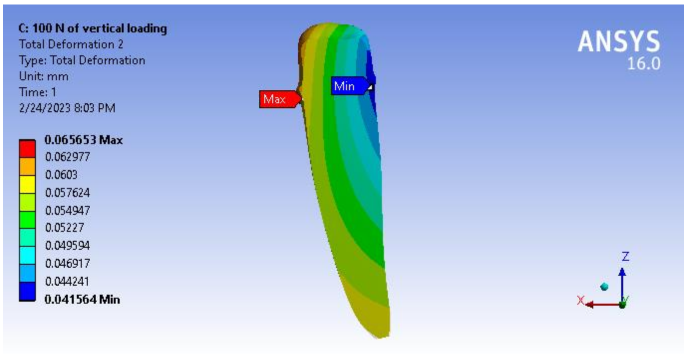

Figure 12: The displacement under vertical load applied on premolar in tooth-implant supported dental prosthesis model.

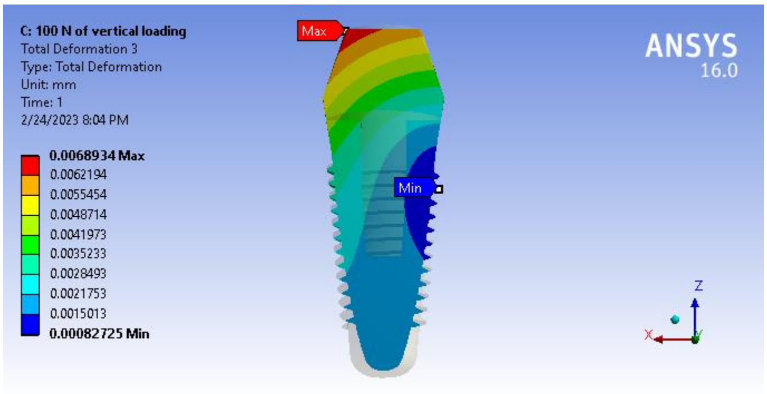

Figure 13: The displacement under vertical load applied on the implant in tooth-implant supported dental prosthesis model.

DISCUSSION

Mathematical modeling has an important place in biomechanics research. The modeling and simulation process saves time and resources for conducting the in vivo experiment or clinical study. However, FEA is most efficient when combined with laboratory experiments. To validate its conclusions, FEA still requires laboratory testing [1].

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 [11,29].

In tooth-supported dental prosthesis model, the micro-displacement results due to vertical 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 [30].

In the tooth-implant supported dental prosthesis model, the displacement results were lower than tooth-supported dental prosthesis, especially the premolar displacement, which is apparently the advantage of using the dental implant as a splint on the natural tooth. In addition, dental implant displacement was less than natural teeth in tooth-supported dental prosthesis model due to lack of periodontal ligament. The difference between natural tooth and dental implant displacement results was consistent with results by D Robinson *et al* [22] their study developed a computational model of a first premolar and a dental implant, as well as evaluating their mechanical responses to loading at the occlusal surface, and the experimental displacement of the dental implant was 60 µm, less than recorded for the natural tooth was 160 µm under 100 N of compressive loading.

CONCLUSION

Based on the study result, it could be concluded that, despite the finite element analysis giving an approximate solution, the finite element simulations did provide a reasonable assessment and a good understanding of the support units' mechanical behavior.

The difference in mobility between natural teeth and implants involved in the same prosthesis has the effect of reducing the micromovement of natural teeth.

REFERENCE

[1] Piccioni MAR V. Application of the Finite Element Method in Implant Dentistry. Appl Finite Elem Method Implant Dent 2008;10:369–77. https://doi.org/10.1007/978-3-540-73764-3.

[2] Wakabayashi N, Ona M, Suzuki T, Igarashi Y. Nonlinear finite element analyses: Advances and challenges in dental applications. J Dent 2008;36:463–71. https://doi.org/10.1016/j.jdent.2008.03.010.

[3] 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.

[4] 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.

[5] 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.

[6] Ky KE. Principles of occlusion in implant dentistry. Interview. Dent Implantol Update 2006;17:33–8. https://doi.org/10.4103/2231-0754.172924.

[7] Qassadi W, Alshehri T, Alshehri A, Alonazi K, Aldhayan I. Review on Dental Implantology 2018;71:2217–25. https://doi.org/10.12816/0045293.

[8] Sykaras N, Iacopino AM, Marker VA, Triplett RG, Woody RD. Implant materials, designs, and surface topographies: their effect on osseointegration. A literature review. Int J Oral Maxillofac Implants 2000;15:675–90.

[9] Trad Turki Toumeh YF and MM. A Literature Review on the Suitability of Dental Tech Implant Ora Systems 2020;7:7–13.

[10] Boldt J, Knapp W, Proff P, Rottner K, Richter E-J. Measurement of tooth and implant mobility under physiological loading conditions. Ann Anat = Anat Anzeiger Off Organ Anat Gesellschaft 2012;194:185–9. https://doi.org/10.1016/j.aanat.2011.09.007.

[11] 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.

[12] Kumar Sm, Jei Jb, Krishnan M. An investigation of effect of rigid and nonrigid connector designs on implant as pier abutment in implant tooth-supported fixed dental prosthesis with three-dimensional finite element analysis: An In vitro study. Adv Hum Biol 2021;11:45. https://doi.org/10.4103/aihb.aihb_55_21.

[13] Jones ML, Hickman J, Middleton J, Knox J, Volp C. A validated finite element method study of orthodontic tooth movement in the human subject. J Orthod 2001;28:29–38. https://doi.org/10.1093/ortho/28.1.29.

[14] 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.

[15] 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.

[16] 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.

[17] 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.

[18] 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.

[19] Kumar GA, Kovoor LC, Oommen VM. Three-dimensional finite element analysis of the stress distribution around the implant and tooth in tooth implant-supported fixed prosthesis designs 2011;1. https://doi.org/10.4103/0974-6781.91283.

[20] Száva DT, Száva A, Száva J, Gálfi B, Vlase S. Dental Implant and Natural Tooth Micro-Movements during Mastication—In Vivo Study with 3D VIC Method. J Pers Med 2022;12:1–19. https://doi.org/10.3390/jpm12101690.

[21] Parfitt GJ. Measurement of the Physiological Mobility of Individual Teeth in an Axial Direction. J Dent Res 1960;39:608–18. https://doi.org/10.1177/00220345600390032201.

[22] Robinson D, Aguilar L, Gatti A, Abduo J, Lee PVS, Ackland D. Load response of the natural tooth and dental implant: A comparative biomechanics study. J Adv Prosthodont 2019;11:169–78. https://doi.org/10.4047/jap.2019.11.3.169.

[23] 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.

[24] 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.

[25] 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.

[26] 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.

[27] 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.

[28] 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.

[29] 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.

[30] 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.