Stress distribution on denture-bearing areas with various thickness of soft denture liner using finite element analysis

Andreas, Ariyani, Ismet Danial Nasution
Specialist Program in Prosthodontics
Faculty of Dentistry, Universitas Sumatera Utara
Medan, Indonesia
Corresponding author: **Ariyani**, e-mail: **ariyanidrg@yahoo.com**

ABSTRACT
Denture-bearing areas in edentulism are unable to tolerate masticatory load because of severe alveolar ridge resorption, which decreases masticatory function in the stomatognathic system. Due to the cushioning effect, the use of soft denture liner (SDL) helps reduce the masticatory load placed upon the denture-bearing areas. The physical properties and thickness of SDL have an impact on the stress distribution and cushioning effect. The masticatory load will harm the alveolar ridge and lead to more severe resorption, when modulus elasticity of SDL lower than the mucosa. The stress distribution of the masticatory load can be analyzed more accurately in-silico study using finite element analysis (FEA) method. In this paper, the stress distribution in denture-supporting areas with various SDL thicknesses is evaluated using FEA. The thickness of SDL contributes to the distribution of stress upon the denture-bearing areas by minimizing the masticatory load. It is concluded that through the same modulus elasticity of the mucosa and SDL is able to equally distribute stress on the denture-bearing areas.
Keywords: stress distribution, denture-bearing area, soft denture liner thickness, finite element analysis

INTRODUCTION

The mastication system, which is one of the stomatognathic systems, is complex with various tissue structures that function simultaneously to produce a functional movement.[1] The mastication system in edentulous patients differs from that in dentulous patients due to resorption conditions and muscle hypotonus, so that it is unable to accept the mastication force and disrupt the functions of the stomatognathic system.[1] According to Riskesdas 2018 data, 29% of the Indonesian population aged 55-64 years old experienced edentulism, and the percentage of edentulous at the age of 65 years and over is 30.6%.[2] Edentulous treatment using complete denture (CD) with heat polymerized acrylic resin (HPAR) material is still often used because it can restore aesthetics, and the mastication function and price are affordable.[3,4] But over time of use, CD can cause effects on the alveolar and mucosal repellent to resorb and atrophy so that patients with this condition will feel pain when using CD and require more complex treatment.[4,5].

The use of soft denture liner (SDL) material can solve this problem because of the cushioning effect, so that the mastication load on complex supporting tissues can be minimized and reduced pain during mastication.[3,6-8] The use of SDL can distribute the mastication load more evenly on the denture-bearing area because the load is partially absorbed by the SDL material.[7] The cushioning effect of SDL material has shock absorption properties so that the voltage distribution can be spread evenly and the mastication load can be minimized, reducing the occurrence of resorption on alveolar linggir.[7,9,10] In some cases of CD and SDL use, there are complaints of pain. This is usually influenced by the thickness of the SDL material, which is not adequate.[11]

The physical properties, composition, and thickness of the SDL material affect the cushioning effect and stress distribution of the SDL against the denture-bearing area.[12] The thicker the SDL, the higher the elasticity.[10] The thickness of the SDL material that is effective in obtaining an optimal cushioning effect and distributing the voltage evenly is 2-3 mm.[9-11] If the use of SDL material is improper, there will be further resorbtion of linggir because when the modulus properties of the elasticity of the SDL material are lower than the mucosa, then the load distributed will be destructive.[10,12,13]

Some methods that can be used to assess the load from mastication to teeth or CD supporting structures are photoelasticity, strain measurement, brittle laquer, and finite element analysis (FEA),[3] that is able to provide information with non-specific properties both qualitatively and quantitatively that can be reproduced from the biomechanical characteristics of dentures and supporting structures without the need for ethical considerations. This method is one of the techniques that is widely used to estimate the load of dentures on supporting tissues and teeth.[3,14]

The purpose of this paper is to assess the stress distribution in the support tissues of dentures of different SDL thicknesses using FEA.

LITERATURE STUDIES

Complete edentulous

Edentulism is the state of being edentulous; with-

DOI: 10.46934/ijp.v4i2.207

out natural teeth, while edentulous is without teeth, lacking teeth.[15] In patients, the ability to accept the mastication load will decrease due to the presence of missing mastication components, such as the teeth and some supporting structures.[1,16] Therefore, edentulous patients tend to choose soft foods and avoid foods that tend to be harder, causing muscle hypotonus. Resorption of residual ridge continues to occur, which will have an impact on disturbances in each function of the stomatognathic system.[1,17,18]

One of the basic functions performed by the stomatognathic system is to collect and grind food, or so-called mastication. Mastication is considered to be the initial phase of food digestion in which the force occurs as a result of movement that interacts complexly between the muscular system, teeth, lips, cheeks, palate, the salivary glands, and temporomandibular joints.[19] In edentulous patients, the mastication system will undergo changes, causing the digestive process that occurs in the mouth to be disturbed, which results in disruption of nutritional intake.[17,18,20] The manufacture of dentures is one of the efforts made to overcome disturbances in the mastication system due to the loss of mastication components.[16]

Removable partial dentures (RPD), implant supported overdenture, and removable CD are some types of dentures that can restore the aesthetics and functionality of edentulous patients.[8,21] As time goes, alveolar bone resorption occurs continuously throughout life and is chronic, progressive, irreversible, and cumulative due to tooth loss.[22,23] However, bone resorption can also be affected by unfavorable mechanical conditions of the prosthesis, resulting in impaired adaptation and retention.[22] These factors can interfere with mastication performance, especially in patients with thin and atrophy mucosa.[22]

Once the patient is edentulous, remodeling of the residual ridge becomes progressive with more resorption in the first-year post-extraction.[24] Although the process of resorption from the alveolar ridge occurs progressively, the rate of this resorption varies from patient to patient. This condition is readily apparent clinically after tooth extraction, but the biology of this process is still not well understood.[25] However, there are several factors that may influence this, namely systemic factors such as the use of drugs, smoking, conditions that affect bone metabolism, and gender. As for the local factors, namely the use of CD and design errors of the CD, which can damage the supporting structure.[24]

Complete dentures

A CD is a fixed or removable dental prosthesis that replaces the entire dentition and associated structures of the maxillae or mandible.[15] The CD is made up of several parts, including a base, flange, border, and artificial teeth.[26.27] In rehabilitating edentulous patients, conventional CD with HPAR material is still the main option because this material has good aesthetics, similar to gingival, as well as easy laboratory procedures.[3,4] Acrylic dentures are also often called mucosal support removable dentures or soft tissue support dentures because the mucous membrane is the foundation or support of the denture.[14.28]

In edentulous patients with mucosa as denture support, it can cause denture instability due to the elastic properties of the mucosa during functional and parafunctional movements in the vertical and lateral or oblique directions. Movement in the lateral direction has the most damaging effect due to displacement of the denture so that the masticatory load is distributed unevenly over the denture-bearing area and there are areas that receive greater pressure than other areas.[1,16,29] When this happens continuously, the mucosa and alveolar bone will be damaged, so the denture base needs to be made as wide as possible and in close contact with the mucosa so that the masticatory load is distributed evenly.[16]

In edentulous patients, the distribution of the load received will change, because the load is not directed directly to the bone but only to the mucosal surface.[30] The oral mucosa has a physiological and mechanical capacity that is quite resistant to pressure because it is composed of epithelium and underlying collagen fibers.[30-33] However, when the mucosa receives too much pressure over a long period of time from the use of GTL, injury can occur to both soft and hard tissue, pain or discomfort, and further ridge resorption and atrophy, which will affect the usage of the denture.[14,21,24,30,35-38]

Although the use of conventional CD is successful in rehabilitating edentulous patients, it is different in edentulous patients with severe resorption of the ridge, the presence of mucosal atrophy, and sharp ridges.[8] This is due to the inability of the ridge to accept occlusal loads during mastication due to pain, so alternative treatment modalities are needed.[6-8,10-12] The alternative treatment that can be done is to line the CD base with a SDL, because this material can absorb the masticatory load and distribute it evenly to the denture-bearing area.[4,7] The SDL materials are also able to increase comfort in denture-wearing patients with atrophic

DOI: 10.46934/ijp.v4i2.207

ridges, thin and non-resilient mucosa, and bruxomania.[7]

Soft denture liner (SDL)

The SDL or called resilient denture liner is an interim (ethylmethacrylate with phthalate plasticizers) or definitive (processed silicone) liner of the intaglio surface of a removable CD, RPD, or intraoral maxillofacial prosthesis.[15] The term *soft liners* refers to the materials that are resilient and used to resurface the intaglio surface of denture bases that receive masticatory loads due to the shock-absorbing properties of these materials so that the load received by the mucosa can be absorbed and distributed evenly so as to reduce pain when the denture is functioning.[39,40]

The SDL are classified based on the term of usage and the type of material. Based on the term of use, it is divided into short-term and long-term. Short-term SDL is a material that is not recommended for more than 30 days of usage (temporary or interim). Short-term SDL is known as tissue conditioner, which is acrylic-based. As for long-term SDL materials, this material can be used for more than 30 days to a year (permanent). This type of long-term SDL also consists of a resin-based which consist of auto-polymerized and heat-polymerized. There is also an acrylic-based which also has auto-polymerized and heat-polymerized.[12,15,40-43]

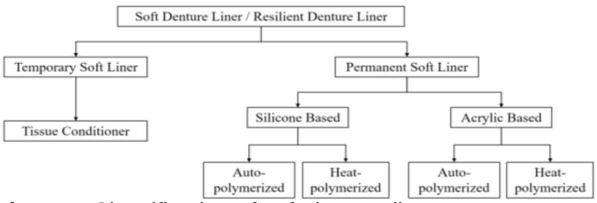

Figure 1 Classification of soft denture liners

In conditions with poor support or foundation (sharp, thin, and atrophic ridge anatomy) causing CD not able to adapt properly to the mucosa. So, when receiving the masticatory load, the CD becomes mobile and tilts, which makes the support area minimal. As a result, the pressure on the mucosa exceeds the average pain threshold limit, causing pain and discomfort in the patient. By lining with SDL material, it can solve the problem due to its nature to absorb stress (shock absorption) and distribute it evenly due to its viscoelasticity properties. The elastic properties of the SDL material on the CD base will increase the contact surface of the denture so that the stress from mastication can be evenly distribute and reduce pain.[7,9,44]

Although the use of SDL material can help overcome these problems by minimizing the masticatory load and reducing pain due to its elastic properties or cushioning effects.[7,9,10] There are still some CD patients with SDL who complain of pain. This is usually caused by the thickness of this material, which is not adequate.[11] The elastic properties of the SDL material are influenced by the thickness, as well as the hardness and modulus of elasticity of the material itself. Because SDL materials and oral mucosa are in essence of two compression springs in series, when SDL materials have higher elasticity than oral mucosa, the majority of the load exerted can be absorbed more and result in a smaller displacement.[10] It can be said that the thickness of the SDL material plays an important role in the distribution of the stress received by the denture-bearing area.[7] The stress distribution of mastication on teeth or supporting structures of CD can be determined by photoelasticity, strain measurement, brittle lacquer, and finite element analysis (FEA).[3]

Finite element analysis

The FEA is a numerical method to obtain an accurate solution to a problem by simulating modeling for later analysis.[45,46] This method was originalnally developed and used in the field of engineering to be a solution to complex physics and engineering problems due to a series of very complicated stages. This development of FEA allows modeling construction to be carried out quickly and effectively, thus playing an important role in the field of engineering.[47]

The use of FEA in the field of medicine has become a testing tool that has developed significantly, especially the use of biomechanical analysis in living things, because it is non-invasive and easy to repeat without the need for duplication.[48] In addition, modeling and treatment can be determined freely as desired, diverse elements can also be combined, the testing process is carried out in one program, and the resulting modeling also has conditions that are identical to the original.[45]

Developments in the field of radiography, such as CT and MRI, make FEA popularly used in the field of dentistry, as it accurately obtains the geometry of bones, both their quality, quantity, and shape.[46.47] The use of FEA in dentistry is, for example, in implants, obturators, restorations, periodondontal ligaments, and trauma and fractures.[49-57]

DISCUSSION

The CD with SDL material is one of the good treatment options to overcome the problem of edentulous patients with severe ridge resorption (flat or

DOI: 10.46934/ijp.v4i2.207

sharp ridges) with a thin, non-resilient layer of mucosa that will cause pain to the mucosa when receiving mastication from the denture.[6,7,40,58] The use of SDL has been widely reported and clinically proven. In a RCT clinical studies, it was also found that the use of SDL increased the mastication ability.[6]

The SDL are classified into several types based on their duration of usage as well as acrylic-based or silicone-based with different viscoelasticity properties of each material.[9,12,58,59] Murata et al, suggest that silicone-based SDL should be first applied to the denture because of its better durability and even though the cushioning effect is lower than that of SDL acrylic. If the patient still feels pain or discomfort, the silicone-based SDL can be replaced with acrylic-based due to the better cushioning effect of this material. Keep in mind, however, that acrylic-based SDL must be replaced on a regular basis due to its material properties and durability being not as good as silicon-based.[42]

The elastic properties of SDL materials are influenced by hardness, modulus of elasticity, and their thickness.[11] However, it is also necessary to pay attention to the mucosa thickness, denture adaption, and arrangement of artificial teeth, as well as the number and direction of the masticatory load, because they affect the amount of the load received by the denture-bearing area.[58] Ideally, a thickness of 2-3 mm SDL is required to obtain an optimal cushioning effect.[9,11] In some studies, it is said that the 3 mm thickness of the SDL material provides optimum resilience, but more than that, it will affect these properties.[12,60] In their research, Murata et al,[42] stated that the most effective thickness of the SDL material is 1.5-2 mm. Lima et al,[13] from FEA results found that the ideal thickness of the SDL material was 2 mm. When the SDL thickness is less or more than ideal, the stress will be greater on the denture-bearing area. This result is also supported by the research conducted by Hussein[2] and Bacchi et al.[61]

However, this is different from what Radi et al,[43] found from the FEA results. The SDL material with a thickness of 2-4 mm reduces the load received by the overdenture implant to the denture-bearing area as the thickness of the SDL material increases. This finding is in agreement with what Santos et al,[62] found from the FEA results. It can be seen that SDL material with a 3 mm thickness provides a more minimal stress on the denture-bearing area than a thickness of 1.5 mm. So, it can be said that increasing the thickness of SDL also increases the cushioning effect of the material itself. However, according to Sato et al,[10] from the FEA results, it was found that the thickness of the SDL material did not play a role in stress distribution. Therefore, to obtain an optimal cushioning effect, we do not always have to choose the most resilient SDL material (low modulus of elasticity).[10] However, when the SDL material has a lower modulus of elasticity than the mucosa, the stress received is not evenly distributed.

The same result was also stated by Shim and Watts, who used the FEA study to look at the stress distribution in CD with SDL, showing that the modulus elasticity of SDL should be the same as with mucosa because SDL material is used to compensate for the loss of thickness of the mucous layer.[10,58,61] The thickness of the soft tissue was also found to not affect the accepted stress ratio, so it is not recommended to use this material with excessive thickness as it can weaken the denture base,[58] despite the fact that the thicker the material, the greater its elasticity. However, that's not always the right choice.[10]

Therefore, the use of SDL materials with an improper thickness will lead to further resorption of the ridge. Due to the lower modulus of elasticity of SDL material than the mucosa, the load will harm the denture-bearing area.[10,12,13] The physical properties, composition, and thickness of the SDL material play a role in the cushioning effect and stress distribution of the SDL material against the denture-bearing area.[13] It is important for clinicians to find out the ideal thickness of the SDL material for distributing the stress evenly to the denture-bearing so that the properties of the SDL material can be utilized optimally.

It is concluded that the use of SDL material of an appropriate thickness is able to distribute the stress evenly to the denture-bearing area and reduce pain during mastication through the same modulus of elasticity between SDL and mucosa.

REFERENCES

1. Sinnurkar S, Shakh SA, Nadiger R. Analysis of changes in bilateral masseter and anterior temporalis muscle efficiency in complete denture wearers:an emg study. Int J Adv Res 2017;5(2): 2672-83.
2. Health Research and Development Agency. Dental and oral health. in: national report on Riskesdas 2018 [Internet] Jakarta: Issuing Institute of the Health Research and Development Agency; 2019.p.179–219.
3. Mousa MA. Biomechanical stress in removable complete dental prostheses: a narrative review of finite element studies. J Int Oral Health 2020;12:413-9.
4. Singh K, Gupta N. Fabrication and relining of dentures with permanent silicone soft liner: A novel way to increase retention in grossly resorbed ridge and minimize trauma of knife edge and severe undercuts ridges. Dent Med Res 2016; 4(1): 24-8.

5. Kovacic I, Persic S, Kranjcic J. Rehabilitation of an extremely resorbed edentulous mandible by short and narrow dental implants. Case Rep Dent 2018; 2018: 1-8.
6. Sadr K. Finite element analysis of soft-lined mandibular complete denture and its supporting structures. J Dent Res Dent Clin Dent Prospect 2012;6(2):37-41.
7. Kouser M. Effect of different denture soft liners on mandibular ridge resorption in complete denture wearers: An In-vivo Study. Int J Sci Study 2021;9(2):38-42.
8. Mangtani N. Effect of resilient liner on masticatory efficiency and general patient satisfaction in completely edentulous patients. J Dent Specialities 2015;3(2):150-5.
9. Chauhan M. An in vitro evaluation of tensile bond strength of commercially available temporary soft liners to different types of denture base resins. J Nat Sc Biol Med 2018;9:263-7.
10. Sato Y, Abe Y, Okane H, Tsuga K. Finite element analysis of stress relaxation in soft denture liner. J Oral Rehabil 2000; 27: 660-3.
11. Agrawal H. A comparison between two ways of relining with soft denture lining materials (an in-vitro study). Sch J App Med Sci 2014; 2(1A):61-66.
12. Lima JBG. Analysis of stress on mucosa and basal bone underlying complete dentures with different reliner material thicknesses: a three-dimensional finite element study. J Oral Rehabil 2013;40(10):767-73.
13. Hussein LA. 3D finite element analysis of the influence of different soft lining materials with variable thicknesses on stress transmitted to underlying mucosa. Int J Adv Res 2014; 2(12):896-905.
14. Zmudzki J, Chladek G, Kasperski J. The influence of a complete lower denture destabilization on the pressure of the mucous membrane foundation. Acta Bioeng Biomech 2012;14(3):67–73.
15. Driscoll CF, Freilich MA, Guckes AD, Knoernschild KL, Mcgarry TJ, Goldstein G, et al. The glossary of prosthodontic terms. 9th Ed. J Prosthet Dent 2017;117(5):e1–105.
16. Hobkirk JA, Zarb G. The edentulous state. In: Prosthodontic treatment for edentulous patients: complete dentures and implant-supported prostheses. 13th ed. Missouri: Elsevier Mosby; 2013.p.1–27.
17. Rath AA. Review edentulism in elderly: a review of current clinical concerns in India. J Geriatr Care Res 2018;5(1):22–7.
18. Şakar O. The effects of partial edentulism on the stomatognathic system and general health. In: Şakar O, editor. Removable partial dentures a practitioners' manual. Switzerland: Springer International Publishing AG; 2016.p.9-16.
19. Kijak E, Margielewicz J, Lietz-Kijak D. Model identification of stomatognathic muscle system activity during mastication. Exp Ther Med 2017; 13: 135-45.
20. Souza VPG de, Assis MV de, Carvalho LF de, Melo JRO, Carvalho FAA. Edentulism and self-perception of oral health in adult and geriatric patients. Braz J Dent 2018;75:1–7.
21. Paras A, Ma S, Waddell JN, Choi JJE. Denture-mucosa pressure distribution and pressure–pain threshold in in vivo, in vitro and in silico studies: a literature review. Oral 2022;2(1):112–25.
22. Campos MFTP, Melo LA, Araújo RFF, Medeiros AKB, Carreiro AFP. Impact of residual ridge anatomy on masticatory efficiency of conventional complete denture users. Rev Gaúch Odontol. 2021;69:e20210059. http://dx.doi.org/10.1590/1981-86372021000592020059
23. Kranjčić J, Stunić MK, Čelebić A. Denture relining as an indicator of residual ridge resorption. Medicinski Glasnik 2013; 10(1): 126-32.
24. Alsaggaf A, Fenlon MR. A case control study to investigate the effects of denture wear on residual alveolar ridge resorption in edentulous patients. J Dent 2020; 98:1-21. https://doi.org/10.1016/j.jdent.2020.103373
25. Pisulkar S, Pohekar A, Borle A, Dahane T. Factors affecting residual ridge resorption: a literature review. Res Rev: J Dent 2019; 10(2):1-7.
26. Rangarajan V, Padmanabhan TV. Textbook of prosthodontics. 2nd ed. New Delhi: Jaypee Borthers Medical; 2017.p.59.
27. Wahab MS,Kassim N, Yussof Y, Rajion ZA. Manufacturing of removable complete dentures using vacuum casting technique. Appl Mech Mater 2012; 120:32-5.
28. Zmudzki J, Chladek G, Kasperski J. Biomechanical factors related to occlusal load transfer in removable complete dentures. Biomech Model Mechanobiol 2015; 14:679–91.
29. Zmudzki J, Chladek G, Malara P. Use of finite element analysis for the assessment of biomechanical factors related to pain sensation beneath complete dentures during mastication. 2018;1–8.
30. Kaur R, Kumar M, Jindal N, Badalia I. Residual ridge resorption–revisited. Dent J Adv Stud 2017; 5(2):76-80.
31. Chen J, Ahmad R, Li W, Swain M, Li Q. Biomechanics of oral mucosa. J Morphol 2015;12(109).
32. Scapino RP. Biomechanics of prehensile oral mucosa. J Morphol 1967;122(2):89–114.
33. Isobe A, Sato Y, Kitagawa N, Shimodaira O, Hara S, Takeuchi S. The influence of denture supporting tissue properties on pressure-pain threshold: Measurement in dentate subjects. J Prosthodont Res [Internet] 2013;57(4):275-83. Available from: http://dx.doi.org/10.1016/j.jpor.2013.07.002
34. Choi JJE, Zwirner J, Ramani RS, Ma S, Hussaini HM, Waddell JN, et al. Mechanical properties of human oral mucosa tissues are site dependent: A combined biomechanical, histological and ultrastructural approach. Clin Exp Dent Res 2020;6(6): 602-11.
35. Kondo T, Kanayama K, Egusa H, Nishimura I. Current perspectives of residual ridge resorption: pathological activation of oral barrier osteoclasts. J Prosthodont Res 2022;
36. Ahmad R, Abu-Hassan MI, Li Q, Swain M V. Three dimensional quantification of mandibular bone remodeling using standard tessellation language registration based superimposition. Clin Oral Implants Res 2013;24(11):1273–9.
37. Chen J, Suenaga H, Hogg M, Li W, Swain M, Li Q. Determination of oral mucosal Poisson's ratio and coefficient of friction from in-vivo contact pressure measurements. Comput Methods Biomech Biomed Engin 2016;19(4):357–65.
38. Jenny N. Beneath the complete denture prosthesis: a review. Int J Dent Sci Res 2018; 6(4): 87-89.
39. Singh K, Gupta N. Fabrication and relining of dentures with permanent silicone soft liner: A novel way to increase retention in grossly resorbed ridge and minimize trauma of knife edge and severe undercuts ridges. Dent Med Res 2016; 4(1): 24-8
40. Kreve S, Dos Reis AC. Denture liners: a systematic review relative to adhesion and mechanical properties. The Scientific World Journal; 2019.
41. Al Taweel SM, Al-Otaibi HN, Labban N. Soft denture liner adhesion to conventional and CAD/CAM processed poly(methylmethacrylate) acrylic denture resins-an in-vitro study. Mater 2021; 14: 6614. https://doi.org/10.3390/ma14216614
42. Murata H. Relationship between viscoelastic properties of soft denture liners and clinical efficacy. Japanese Dent Sci Rev 2008; 44:128-32.

DOI: 10.46934/ijp.v4i2.207

43. Radi IAbd-E. Effect of two different soft liners and thicknesses mediating stress transfer for immediately loaded 2-implant supported mandibular overdentures: A finite element analysis study. J Prosthet Dent 2016;116(3):356-61.
44. Rathi S, Verma A. Resilient liners in prosthetic dentistry: An update. Int J Appl Dent Sci 2018; 4(3): 34-8.
45. Erhunmwun ID, Ikponmwosa UB. Review on finite element method. J Appl Sci Environ Manag 2017;21(5):999.
46. Szabó B, Babuška I. Finite element analysis method, verification and validation. 2nd ed. New Jersey: John Wiley & Sons, Inc.; 2021.p.1-387.
47. Ebrahimi F. Finite element analysis: new trends and developments. 2nd ed. Qazvin: ExLi4EvA; 2016.
48. Trivedi S. Finite element analysis: A boon to dentistry. J Oral Biol Craniofac Res [Internet] 2014;4(3):200-3. Available from: http://dx.doi.org/10.1016/j.jobcr.2014.11.008.
49. Lu S, Li T, Zhang Y, Lu C, Sun Y, Zhang J, et al. Biomechanical optimization of the diameter of distraction screw in distraction implant by three-dimensional finite element analysis. Comput Biol Med [Internet] 2013;43(11):1949-54. Available from: http://dx.doi.org/10.1016/j.compbiomed.2013.08.019
50. Shigemitsu R, Yoda N, Ogawa T, Kawata T, Gunji Y, Yamakawa Y, et al. Biological-data-based finite-element stress analysis of mandibular bone with implant-supported overdenture. Comput Biol Med [Internet] 2014;54:44-52. Available from: http://dx.doi.org/10.1016/j.compbiomed.2014.08.018
51. Verri FR, Batista VEDS, Santiago JF, Almeida DADF, Pellizzer EP. Effect of crown-to-implant ratio on peri-implant stress: A finite element analysis. Mater Sci Eng C [Internet]. 2014;45:234-40. Available from: http://dx.doi.org/10.1016/j.msec.2014.09.005
52. De Sousa AA, Mattos BSC. Finite element analysis of stability and functional stress with implant-supported maxillary obturator prostheses. J Prosthet Dent [Internet]. 2014;112(6):1578–84. Available from: http://dx.doi.org/10.1016/j.prosdent.2014.06.020
53. Liu S, Liu Y, Xu J, Rong Q, Pan S. Influence of occlusal contact and cusp inclination on the biomechanical character of a maxillary premolar: A finite element analysis. J Prosthet Dent [Internet] 2014;112(5):1238-45. Available from: http://dx.doi.org/10.1016/j.prosdent.2014.04.011
54. Tuna M, Sunbuloglu E, Bozdag E. Finite element simulation of the behavior of the periodontal ligament: A validated nonlinear contact model. J Biomech [Internet] 2014;47(12):2883-90. Available from: http://dx.doi.org/10.1016/j.jbiomech.2014.07.023
55. 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 [Internet] 2013;8(2):121-8. Available from: http://dx.doi.org/10.1016/j.jds.2013.01.001
56. Huempfner-Hierl H, Schaller A, Hemprich A, Hierl T. Biomechanical investigation of naso-orbitoethmoid trauma by finite element analysis. Br J Oral Maxillofac Surg [Internet] 2014;52(9):850-3. Available from: http://dx.doi.org/10.1016/j.bjoms.2014.07.255
57. Santos LSDM, Rossi AC, Freire AR, Matoso RI, Caria PHF, Prado FB. Finite-element analysis of 3 situations of trauma in the human edentulous mandible. J Oral Maxillofac Surg [Internet] 2015;73(4):683-91. Available from: http://dx.doi.org/10.1016/j.joms.2014.10.014
58. Kouser M. Soft denture liner adhesion to conventional and CADCAM processed poly(methyl methacrylate) acrylic denture resins-an in-vitro study. Mater 2021; 14(6614):1-10.
59. Shrivastava R. Stress distribution under commercial denture liners-a finite element & clinical analysis. J Clin Diagn Res 2016; 10(12):14-8.
60. Shah RJ, Shah SG. A Technique to guide and measure the reduction of a processed mandibular complete denture for resilient soft liner. J Dent Mater Tech 2014; 3(4): 139-43.
61. Bacchi A. Influence of different mucosal resiliency and denture reline on stress distribution in per-implant bone tissue during osseointegration. A three-dimensional finite element analysis. Gerodontol 2012; 29:833-7.
62. Santos MB, Bacchi A. Influence of thickness and area reline on the stress distribution in periimplant bone during the healing period: a three dimensional finite element analysis. Gen Dent 2012; 60:231-6.

DOI: 10.46934/ijp.v4i2.207