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DEPARTAMENTO DE MATERIAIS ODONTOLÓGICOS E PRÓTESE

RICARDO FANTASIA

Distribuição de tensão sobre implantes durante fase de osseointegração de pacientes desdentados totais sob diferentes tipos de implantes e cicatrizadores: Estudo por análise de elementos finitos 3D.

Araçatuba

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Dissertação apresentada à Faculdade de Odontologia de Araçatuba da Universidade Estadual Paulista "Júlio de Mesquita Filho" UNESP, para a obtenção do título de Mestre em Ciência Odontológica – Área de Concentração em Biomateriais.

Orientador: Prof. Associado Fellippo Ramos Verri

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Dedicatória

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Epígrafe

"Um pouco de ciência nos afasta de Deus. Muito, nos aproxima."

Profº Dr. Louis Pasteur, 1892

Fantasia, R. **Distribuição de tensão sobre implantes durante fase de osseointegração de pacientes desdentados totais sob diferentes tipos de implantes e cicatrizadores. Estudo por**

análise de elementos finitos 3D. 27 f. 2022. Dissertação (Mestrado) - Faculdade de Odontologia, Universidade Estadual Paulista, Araçatuba, 2022.

O objetivo desse estudo foi avaliar o estresse gerado no tecido ósseo, implantes e tampas de cicatrização ao usar diferentes alturas de cicatrizadores e diferentes conexões (HE e Cone Morse) em duas situações distintas de carregamento (vertical e oblíqua) em *overdenture* ou em prótese do tipo protocolo em mandíbula, por análise de elementos finitos tridimensionais (3D). Quatro modelos 3D foram elaborados usando imagem digitalizada de um modelo mandibular de laboratório e prótese total, incluindo 4 implantes colocados no nível da crista na região dos dentes #46, #43, #33 e #36. Foi simulado osso tipo II, separando os tecidos moles. O design do implante/tampa de cicatrização foi obtido a partir de componentes originais. Foram modeladas tampas de cicatrização de cone morse e hexágono externo de 2,5mm e 4,5mm. Foram aplicados sobre a prótese total 256,2N de carga vertical (0°) e oblíqua (45°). A análise de deslocamento e tensão de von Mises e máxima tensão principal foi realizada usando o ANSYS 19.2. A carga vertical não mostrou diferenças significativas na distribuição de tensão variando tampas de cicatrização ou conexões de implantes. O carregamento oblíquo mostrou maior concentração de tensão em coroas de maior altura e para modelos com implantes de hexágono externo. Portanto, conclui-se que de acordo com os resultados e limitações deste estudo, coroas de maior altura afetam negativamente a transmissão de tensões às estruturas de suporte independentemente da conexão do implante e os implantes de hexágono externo são mais prejudiciais à transferência de tensões principalmente para situações de altas alturas de coroas de cicatrização.

Descritores: Análise de elementos finitos; Projeto do Implante Dentário-Pivô; Fenômenos mecânicos; Implantes dentários, Prótese total.

Fantasia, R. **Influence of healing caps heights and implant connections on stress distribution in initial osseointegration of implants placed to fabrication of mandibular protocol/overdentures prosthesis : study by 3D finite element analysis** . 27 f. 2022.

Dissertação (Mestrado) - Faculdade de Odontologia, Universidade Estadual Paulista, Araçatuba, 2022.

Abstract:

To evaluate the stress generated on bone tissue, implant, and healing caps while using different heights of caps and different connections in two different loading situations of mandibular overdenture/protocol situation by 3D finite element analysis. Materials and methods: Four 3D models were modeled using scanned image of a laboratory mandibular model and complete denture, including 4 implants placed at crestal level in region of teeth #46, #43, #33 and #36. Type II bone was simulated, separating soft tissue. The implant/healing cap design was obtained from original components. Healing caps of morse taper and external hexagon of 2,5mm and 4,5mm were modeled. 256,2N of vertical (0°) and oblique (45°) loadings were applied over complete denture. Displacement and stress analysis of von Mises and Maximum Principal Stress were performed using ANSYS 19.2. Results: Vertical loading did not show differences in stress distribution varying healing caps or implant connections. Oblique loading showed more stress concentration in healing caps of higher heights and for models using external hexagon implants. Conclusions: According to the results and limitations of this study healing caps of higher heights negatively affect the stress transmission to the supporting structures independently of implant connection and external hexagon implants were more prejudicial to the stress transferring mainly for situations of high heights of healing caps.

Keywords: Finite element analysis; Dental Implant-Abutment Design; Mechanical phenomena; Dental implants, Denture, Complete.

Sumário

Fantasia R. **Influence of healing caps heights and implant connections on stress distribution in initial osseointegration of implants placed to fabrication of mandibular protocol/overdentures prosthesis. Study by 3D finite element analysis.** [Dissertação](Mestrado). Araçatuba: UNESP — Univ. Estadual Paulista; 2022.

PURPPOSE

Objectives: To evaluate the stress generated on bone tissue, implant, and healing caps while using different heights of caps and different connections in two different loading situations of mandibular overdenture/protocol situation by 3D finite element analysis. Materials and methods: Four 3D models were modeled using scanned image of a laboratory mandibular model and complete denture, including 4 implants placed at crestal level in region of teeth #46, #43, #33 and #36. Type II bone was simulated, separating soft tissue. The implant/healing cap design was obtained from original components. Healing caps of morse taper and external hexagon of 2,5mm and 4,5mm were modeled. 256,2N of vertical (0°) and oblique (45°) loadings were applied over complete denture. Displacement and stress analysis of von Mises and Maximum Principal Stress were performed using ANSYS 19.2. Results: Displacement maps showed no differences and clinically acceptable values for all models. Vertical loading did not show differences on stress distribution varying healing caps or implant connections. Oblique loading showed more stress concentration in healing caps of higher heights and for models using external hexagon implants. Conclusions: According to the results and limitations of this study healing caps of higher heights negatively affect the stress transmission to the supporting structures independently of implant connection and external hexagon implants were more prejudicial to the stress transferring mainly for situations of high heights of healing caps.

Keywords: Finite element analysis; implant abutment; mechanical phenomena; dental implants, complete denture.

INTRODUCTION

Implantology allowed to make dental rehabilitations with high success rate and long follow-up, being indicated to a lot of patients, including complete dentures users that had been described the most benefited by implants since there is an improvement of comfort.[1-2] Primary stability has been demonstrated as the main factor in the success or failure of implants since the initial biologic fixation facilitates the continuous apposition / re-modeling of bone.[3-4]

After implant placement, clinical and mechanical factors affect the osseointegration including the initial cicatricial phase and post-prosthesis installation. From a biomechanical point of view, physiologic loads over implants, mainly compressive, are well dissipated by bone tissue; however, unphysiological high tension could generate peri-implantitis and its evolution create peri-implant bone resorption, and consequently implant failure.[5-6]

Independent of treatment time, micro-movements over 150 microns could result in osseointegration failure.5-9 The etiology includes micro bleeding that could induce fibrotic tissue formation on the peri-implant region. Therefore, in the initial time of osseointegration no overload to induce excessive movement to the implant. However, unfortunately, it is commonly for edentulous patients the rehabilitation with provisional complete denture prosthesis over the soft tissue or healing caps could induce stress to the implants. Moreover, if the comfort of the patient is improved by better occlusion force the provisional prosthesis could distribute more stress than conventional complete dentures.[10]

Clinically, there are two ways to allow osseointegration during the first step surgery time: conventional two step surgery protocol or positioning healing caps directly over the implants after surgery if they achieve good primary stability. In this last situation, the soft tissue heals with the healing cap exposed in the oral cavity and have been called by some authors as non submerge technique.[11-15] Using submerge technique as priorly described by Branemark always have need a second stage surgery to connect prosthetic abutment and loading. This protocol is justified to minimize the risk of infection during the osseointegration phase.[16] However, the non-submerged technique has gained popularity as it reduces surgical intervention, thus reducing surgical time, patient discomfort as well as produces healed/healthy peri-implant mucosa at the time of prosthetic rehabilitation. The studies have been described with similar and satisfactory osseointegration results.[13, 17-18]

The non-submerged protocol is extremely interesting cause reduces surgery time and number, healing time, improves comfort to the patient[19] and some articles show less marginal bone loss with better crestal bone and soft tissue level maintenance with similar success rates.[20-23] In this way, since good primary stability is achieved, the non-submerged technique can be indicated.[17]

The initial two-stage protocol described by Branemark was made over external hexagon implant indication. However, with the improvement and popularity of implantology, other implant connections were developed, like morse taper, trying to improve the biomechanics of stress distribution.[24-25] Mechanically, some authors stated that this implant could provide more controlled stress distribution[26] and being more stable when compared to external hexagon implants.[27] Therefore, using morse taper implants could be more favorable when considering the use of a non-submerged technique.

Biomechanical studies verify if these differences could be useful to improve the understanding of clinical usage of these techniques in implantology. The finite element method allows this evaluation and has been widely used for this goal.[28] Some reports using this methodology analyzed the effect of stress distribution over complete dentures,[29-30] but not considering the implant connection or different heights of healing caps in non-submerged techniques, including only vertical load conditions that physiologically are more favorable to implantology.

Therefore, the present study aimed to evaluate the stress generated on the implant, healing cap and bone tissue while using and external hexagon or morse Taper connection and 2.5 and 4.5 mm of healing cap, heights under vertical and oblique loading by 3D finite element analysis in situations of the mandibular 4-implant supporting prosthesis and in the first stage of osseointegration.

The null hypothesis was that there would not be any difference in the stress distribution on the implant and supporting structures when the implant connection is changed; and that there would not be any difference in the stress distribution on the implant and supporting structures when the height of the healing caps is changed.

MATEIRAL AND METHODS

Four tridimensional models were modeled simulating bone type II and varying the implant connection simulated (morse taper and external hexagon) and the height of the healing cap being or at soft tissue level or 2 mm exposed. A full description of the models is presented at Table 1.

The bone tissue modeling was made by scanning of outer surface of one mandibular laboratorial model including a complete denture adapted over it using teeth and a prosthesis base as a unique structure. The models with the variations were presented in Figure 1. All scanned images were obtained by “STL” archive format and exported to Rhinoceros 3D 4.0 (NURBS Modeling for Windows, Robert McNeel & Associates, Seattle, USA) to modeling phase and simplifications by separating layers of mucosa and cortical bone with mean of 2mm and 1 mm thickness, respectively methodology of previous studies.[28, 31-32]

The geometry of implants was made using the original design of morse taper 3.5x10mm UNITITE (SIN, Sistema de Implante Nacional, São Paulo/SP, Brazil) of the Solidworks (SolidWorks Corp, Massachusetts, EUA) and exporting in .stp file format to Rhinoceros 3D following simplification of surfaces but allowing computational processing without loss of information of original design for FEA method. For direct comparison, the external geometry of morse taper implant was fixed and was made simulation of an external hexagon connection as previously published. [28, 31-32] Healing caps were modeled to achieve soft tissue level and to be exposed in 2mm over tissue level and maintained the same height for both implants. The position of each implant was made by tooth reference using #46, #43, #33 and #36 positions always at crestal bone level. A detailed presentation of the models created is illustrated in Figure 1.

Finite element analysis was made by Ansys 19.2 (Southpointe, PA, USA). The meshing processing was made using CFD (Computational Fluid Dynamics) to allows high resolution in complex surfaces. The number of nodes/elements of each model was 159812/5884858, 1168345/5929014, 965553/4863938 and 971197/4894768 for models M1, M2, M3 and M4, respectively. The mechanical properties of all simulated materials were presented in the Table 2 and was obtained from the literature and considered all isotropic, homogeneous, and linearly elastic.

Two types of contact were simulated: *"no separation"* to denture/healing caps and denture/soft tissue contacts; and *"bonded"* to all other contacts. Restrictions of models were assumed in *"x, y* and *z"* directions and applied to a distal section of bone tissue (cortical and trabecular). The simulated loads were applied vertically and oblique at 45 degrees directly on the occlusal teeth region distributing a total of 256,2N of load according to values obtained from the study of Alvarez-Arenal et al., 2014.[35] Maps of displacement, von Mises and Maximum Principal Stress maps were generated to illustrate the results.

RESULTS

Displacement maps are showed in Figure 2. It is possible to verify that all models have similar displacement distribution for both loads application independent of connection type or healing height. Values of oblique loading are higher than vertical ones achieving almost two times in the anterior region; however, presenting inferior data of 0,06mm on cortical bone. Region of implant #33 was relieved in oblique load for all models when compared to vertical loading being the displacement increased in the #43 implant region.

von Mises maps of bone and implants/healing caps shows that oblique loading was more harmful to concentrate stress in the side of application of load (implants #43 and #46) (Figure 3). However, no difference between models despite between oblique force it seems M4 presented more stress concentration on healing caps of implants #43 and #46. In this way, an individualization of implant and healing caps was made. These maps are illustrated on Figure 4. In this figure it is possible to verify that healing caps with more height tend to present more stress concentration to the implant independent of loading direction or implant connection. Oblique loading showed more stress than vertical loading (almost 4 times) more in the cervical region of the implant. No difference was observed between implant connections does not show difference for vertical loading; however, in oblique loading, the cervical region of the implant presented a slightly more stress concentration for external hexagon implants, mainly for healing caps of 4,5mm (M4).

Maximum principal stress maps of bones are presented in Figure 5. In vertical loading no visible difference comparing was observed all models. Oblique loading showed that implant #43 presented higher values of compressive and tensile stress and no difference observed comparing healing caps of different heights, but direct comparison of different implant connections showed that models with external hexagon implants (M3 and M4) presented higher tractive stress concentration on lingual region of cortical bone of implant #43 (arrows in figure 5).

DISCUSSION

The non-submerged technique. According to the of this study the null hypothesis was partially rejected cause some differences on stress distribution was observed when varying the implant connection and the height of healing caps for oblique loading.

Despite the biomechanical differences in stress distribution of different implant connections[24-27] the situation analyzed in this study is a little bit different since the stress transferred to the supporting structures is not the same amount as a fixed implant supported prosthesis.[35] In this way, is quite to expect that yield or ultimate tensile strength of materials involved in this study will never be achieved. However, even considering these differences it seems that external hexagon implants show more stress distribution to the bone in the cervical implant neck than morse taper implants and healing caps of higher height were more prejudicial to stress transferring too. Since a higher lever arm is expected with higher heights of healing caps this result was not surprising and it agrees with other studies.[29] It is necessary to clarify that macro design of implant tested in this study was the same for both connections.

Displacement maps showed values similar that clinically expected and no visible difference between models. In this way, slightly difference in stress distribution in the von Mises and Maximum Principal Stress maps could impact the longevity of implants in the initial healing phase of osseointegration process is questionable. However, some studies have described the use of soft materials for relining denture bases in this phase to decrease the stress transferring.[29-30] Clinically, the observation tends to be worrying about this situation since patients feel comfortable supporting over the healing caps and usually occlude by forcing the denture in these structures.

There is feel studies involving 3D FEA methodology to compare results with this study.[29] However, the results of this study are in agreement then since indicated that the exposure of the healing caps during the healing period may be considered a potential risk, mainly when the prosthesis is not relined with soft liner materials and the healing caps at the gingival level should be used after one-stage implant surgery or reopening the implants cause transfer less stress to the supporting structures. Is it important to highlight that the comparative prior study was made with only 2 implants, simplified to the smooth cylindrical surface since convergency testing resulted in no difference for study, using 4x10mm size of implant and not specified the implant connection. [29]

Another interesting point of discussion is about the quality of soft tissue around the implants. In this study it was simulated a 2mm thickness of soft tissue that could be considered medium biotype. The literature describes that peri-implant tissue biotype is an intrinsic parameter that affects both the esthetic and functional aspects of implant rehabilitation by influencing the remodeling of hard and soft tissues and thick biotype is a desirable feature providing more predictable surgical and prosthetic outcomes.[36] Clinically is observed that thin biotypes present mucositis more frequently.

Finally, it is obvious that non-submerged technique is preferable than submerged technique thinking about patient comfort and satisfaction.[19] However, the real influence of implant connection and healing height in this specific situation of complete provisional dentures on the initial phase of osseointegration is not a consensus. It is necessary to clarify that a lot of clinical studies that presented advantages of non-submerged techniques describes situations involving implants supporting single unit prosthesis[21-23] where there is less stress transferring to the supporting structure caused by the presence of adjacent teeth. However, considering complete dentures it is impossible not to transfer some stress to the healing caps. In this way, considering the limitations and the design of this computational study, it seems the non-submerged technique remains controverse and in agreement with some studies.[37] Thus, if low levels of stress impair the initial healing of implants, especially in the first postoperative days, further studies may be necessary to assess this situation.

CONCLUSION

According to the results and limitations of this study the following conclusions were drawn: healing caps of higher heights affect negatively the stress transmission to the supporting structures independently of implant connection; external hexagon implants transfers more stress to the supporting structures being more prejudicial when compared to morse taper implants mainly for high heights of healing caps situations.

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References

1. AlTarawneh S, Thalji G, Cooper L. Full-arch implant-supported monolithic zirconia fixed dental prostheses: An updated systematic review. Int J Oral Implantol (Berl). 2021;14(1):13-22.
2. Geertman ME, Boerrigter EM, vanWaas MA, van Oort RP. Clinical aspects of a multicenter clinical trial of implant retained mandibular overdentures in patients with severely resorbed mandibles. J Prosthet Dent 1996;75:194-204.

3. Chang PC, Lang NP, Giannobile WV. Evaluation of functional dynamics during osseointegration and regeneration associated with oral implants. Clin Oral Implants Res 2010;21:1–12.
4. Berglundh T, Abrahamsson I, Lang NP, Lindhe J. De novo alveolar bone formation adjacent to endosseous implants. Clin Oral Implants Res. 2003 Jun;14(3):251-62. doi: 10.1034/j.1600-0501.2003.00972.x.
5. Flanagan D, Ilies H, Lasko B, Stack J. Force and movement of non-osseointegrated implants: an in vitro study. J Oral Implantol 2009;35:270–6.
6. Brunski JB. In vivo bone response to biomechanical loading at the bone/dental-implant interface. Adv Dent Res 1999;13:99–119.
7. Fazel A, Aalai S, Rismanchian M, Sadr-Eshkevari P. Micromotion and stress distribution of immediate loaded implants: a finite element analysis. Clin Implant Dent Relat Res 2009;11:267–71.
8. Chong W, Davliakos JP, Fischman B, Saadoun AP, Takacs G. Immediate loading. Implant Dent 2002;11:315–23.
9. Szmukler-Moncler S, Salama H, Reingewirtz Y, Dubruille JH. Timing of loading and effect of micromotion on bone-dental implant interface: review of experimental literature. J Biomed Mater Res 1998;43:192–203.
10. Fontijn-Tekamp FA, Slagter AP, Van Der Bilt A, et al. Biting and chewing in overdentures, full dentures, and natural dentitions. J Dent Res. 2000;79(7):1519-1524. doi:10.1177/00220345000790071501
11. Cochran DL, Douglas HB. Augmentation of osseous tissue around nonsubmerged endosseous dental implants. Int J Periodont Restorat Dent 1993;13:506-19.

12. Lang NP, Berglundh T, Heitz-Mayfield LJ, Pjetursson BE, Salvi GE, Sanz M. Consensus statements and recommended clinical procedures regarding implant survival and complications. Int J Oral Maxillofac Implants 2004;19:150-4.
13. Cecchinato D, Olsson C, Lindhe J. Submerged or non-submerged healing of endosseous implants to be used in the rehabilitation of partially dentate patients. J Clin Periodontol. 2004 Apr;31(4):299-308. doi: 10.1111/j.1600-051X.2004.00527.x. PMID: 15016259.
14. Chrcanovic BR, Albrektsson T, Wennerberg A. Reasons for failures of oral implants. J Oral Rehabil. 2014 Jun;41(6):443-76. doi: 10.1111/joor.12157. Epub 2014 Mar 11.
15. Chatzopoulos GS, Wolff LF. Dental implant failure and factors associated with treatment outcome: A retrospective study. J Stomatol Oral Maxillofac Surg. 2022 Oct 21:S2468-7855(22)00328-7. doi: 10.1016/j.jormas.2022.10.013. Epub ahead of print.
16. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;10:387-416.
17. Mumcu E, Bilhan H, Geckili O. The influence of healing type on marginal bone levels of implants supporting mandibular overdentures: A randomized clinical study. Indian J Dent Res 2012;23:514-8.
18. Ferrigno N, Laureti M, Fanali S, Grippaudo G. A long-term follow-up study of non-submerged ITI implants in the treatment of totally edentulous jaws: Part I: Ten-year life table analysis of a prospective multicenter study with 1286 implants. Clin Oral Implants Res 2002;13:260-73.

19. Becker W, Becker BE, Israelson H, Lucchini JP, Handelsman M, Ammons W, et al. One-step surgical placement of Brånemark implants: A prospective multicenter clinical study. Int J Oral Maxillofac Implants 1997;12:454-62.

20. Hermann JS, Buser D, Schenk RK, Schoolfield JD, Cochran DL. Biologic width around one- and two-piece titanium implants. Clin Oral Implants Res 2001;12:559-71.

21. Kim YK, Kim SG, Oh HK, Choi YG, Cho YS, Oh YH, et al. Evaluation of peri-implant tissue in nonsubmerged dental implants: A multicenter retrospective study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:189-95.

22. Behneke A, Behneke N, d'Hoedt B, Wagner W. Hard and soft tissue reactions to ITI screw implants: 3-year longitudinal results of a prospective study. Int J Oral Maxillofac Implants 1997;12:749-57.

23. Cecchinato D, Bengazi F, Blasi G, Botticelli D, Cardarelli I, Gualini F. Bone level alterations at implants placed in the posterior segments of the dentition: Outcome of submerged/non-submerged healing: A 5-year multicenter, randomized, controlled clinical trial. Clin Oral Implants Res 2008;19:429-31.

24. Koutouzis T, Neiva R, Nonhoff J, Lundgren T. Placement of implants with platform-switched Morse taper connections with the implant-abutment interface at different levels in relation to the alveolar crest: a short-term (1-year) randomized prospective controlled clinical trial. Int J Oral Maxillofac Implants. 2013;28(6):1553-1563. doi:10.11607/jomi.3184

25. Valles C, Rodríguez-Ciurana X, Clementini M, Baglivo M, Paniagua B, Nart J. Influence of subcrestal implant placement compared with equicrestal position on the peri-implant hard and soft tissues around platform-switched implants: a

systematic review and meta-analysis. Clin Oral Investig. 2018;22(2):555-570. doi:10.1007/s00784-017-2301-1

26. de Faria Almeida DA, Pellizzer EP, Verri FR, Santiago JF Jr, de Carvalho PS. Influence of tapered and external hexagon connections on bone stresses around tilted dental implants: three-dimensional finite element method with statistical analysis. J Periodontol. 2014;85(2):261-269. doi:10.1902/jop.2013.120713

27. Paganelli OEB, Santos PL, Spin-Neto R, Pereira-Filho VA, Margonar R. Stability of mandibular implants with Morse taper and external hexagon connections placed under immediate loading: a longitudinal clinical study. Gen Dent. 2022;70(2):50-54

28. Verri FR, Santiago Júnior JF, Almeida DA, Verri AC, Batista VE, Lemos CA, Noritomi PY, Pellizzer EP. Three-Dimensional Finite Element Analysis of Anterior Single Implant-Supported Prostheses with Different Bone Anchorages. Scientific World Journal 2015;2015:321528.

29. dos Santos MB, Da Silva Neto JP, Consani RL, Mesquita MF. Three-dimensional finite element analysis of stress distribution in peri-implant bone with relined dentures and different heights of healing caps. J Oral Rehabil 2011; 38:691–6.

30. Radi IA, Elmahrouky N. 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):356-361. doi:10.1016/j.prosdent.2016.01.031

31. Verri FR, Batista VEDS, Santiago Jr. JF, Almeida DADF, Pellizzer EP. Effect of crown-to-implant ratio on peri-implant stress: a finite element analysis. Materials Science & Engineering C: Materials for Biological Applications 2014;45:234–40.

32. Ramos Verri F, Santiago Junior JF, de Faria Almeida DA et al. Biomechanical influence of crown-to-implant ratio on stress distribution over internal hexagon short implant: 3-D finite element analysis with statistical test. Journal of Biomechanics 2015;48(1):138–45.
33. Barao VA, Assuncao WG, Tabata LF, de Sousa EA, Rocha EP. Effect of different mucosal thickness and resiliency on stress distribution of implantretained overdentures-2D FEA. Comput Methods Programs Biomed 2008; 92: 213–23.
34. Kawasaki T, Takayama Y, Yamada T, Notani K. Relationship between the stress distribution and the shape of the alveolar residual ridge–three-dimensional behaviour of a lower complete denture. J Oral Rehabil 2001;28:950–7.
35. Alvarez-Arenal A, Brizuela-Velasco A, DeLlanos-Lanchares H, Gonzalez-Gonzalez I. Should oral implants be splinted in a mandibular implant-supported fixed complete denture? A 3-dimensional-model finite element analysis. J Prosthet Dent 2014; 112(3):508-14.
36. Lee A, Fu JH, Wang HL. Soft tissue biotype affects implant success. Implant Dent. 2011 Jun;20(3):e38-47. doi: 10.1097/ID.0b013e3182181d3d. PMID: 21613940.
37. Choi BH, Li J, Kim HS, Ko CY, Jeong SM, Xuan F. Comparison of submerged and nonsubmerged implants placed without flap reflection in the canine mandible. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2008 May;105(5):561-5. doi: 10.1016/j.tripleo.2007.08.020. Epub 2008 Mar 4. PMID: 18299237.

Table List

Figure Legends

FIGURE 1 - Schematic description of models showing individualized structures. (a) complete denture (base and teeth); (b) soft tissue (mucosa); (c) healing caps; (d) implants (region of tooth #46, #43, #33 and #36; (e) cortical bone; (f) trabecular bone.

FIGURA 2 - General displacement maps of bones and implants/healing caps (unit = mm)

FIGURA 3 - General von Mises maps of bones and implants/healing caps (unit = MPa)

FIGURA 4 - Von Mises maps of implants/healing caps (unit = MPa)

FIGURA 5 - General Maximum Principal Stress maps of bones (unit = MPa)

TABLE 1 - Description of models of study

Model	Implants	Implant connection	Healing cap
M1	4 x 3,5x10mm	Morse taper	2.5mm (at soft tissue level)
M2	4 x 3,5x10mm	Morse taper	4.5mm (2mm exposed)
M3	4 x 3,5x10mm	External hexagon	2.5mm (at soft tissue level)
M4	4 x 3,5x10mm	External hexagon	4.5mm (2mm exposed)

TABLE 2 - Mechanical properties of all simulated materials

Material	Elasticity modulus (E-GPa)	Poisson's coefficient (*ν*)	Reference
Cortical bone	13.7	0.30	27
Trabecular bone	1.37	0.30	27
Soft tissue (mucosa)	0.34	0.45	32
Titanium	110	0.35	27
Acrylic resin (teeth and base)	1.96	0.30	33

Figure 1 - Schematic description of models showing individualized structures. (a) complete denture (base and teeth); (b) soft tissue (mucosa); (c) healing caps; (d) implants (region of tooth #46, #43, #33 and #36; (e) cortical bne; (f) trabecular bone.

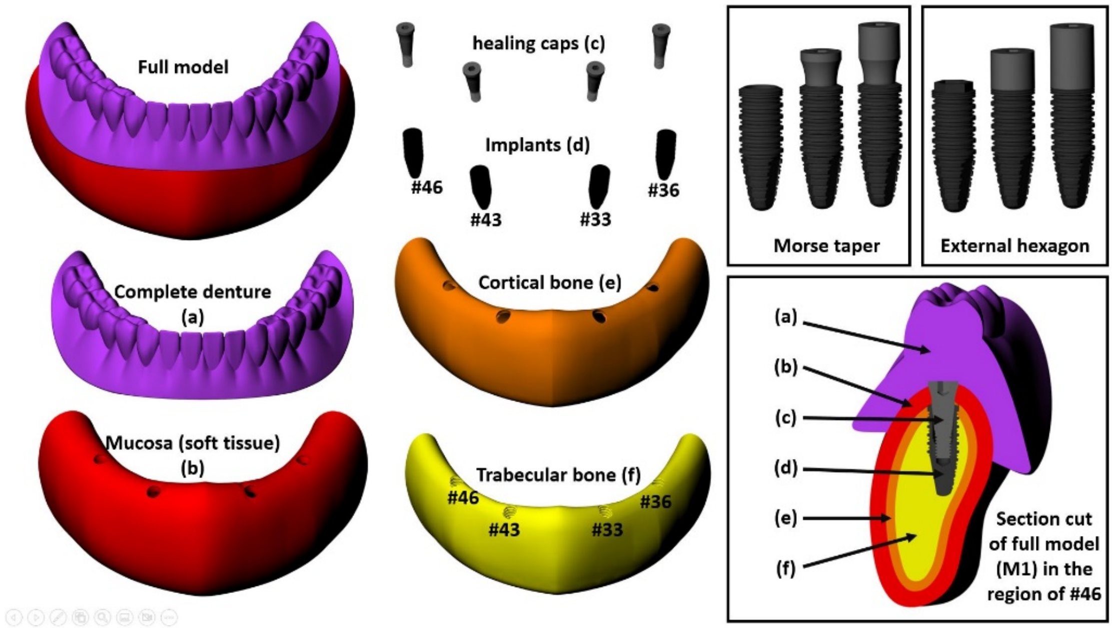

Full model
Complete denture
(a)
Mucosa (soft tissue)
(b)
healing caps (c)
Implants (d)
#46
#43
#33
#36
Cortical bone (e)
Trabecular bone (f)
#46
#36
#43
#33
Morse taper
External hexagon
(a)
(b)
(c)
(d)
(e)
(f)
Section cut
of full model
(M1) in the
region of #46

Figure 2 - General displacement maps of bones and implants/healing caps (unit = mm)

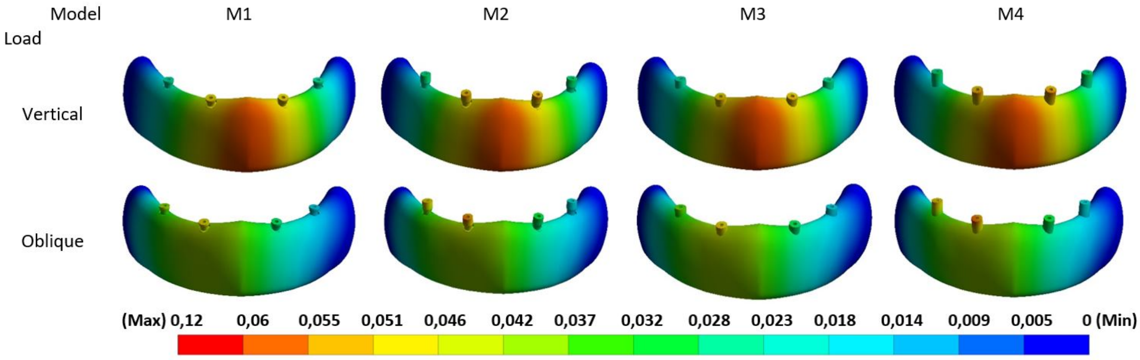


Figure 3 - General von Mises maps of bones and implants/healing caps (unit = MPa)

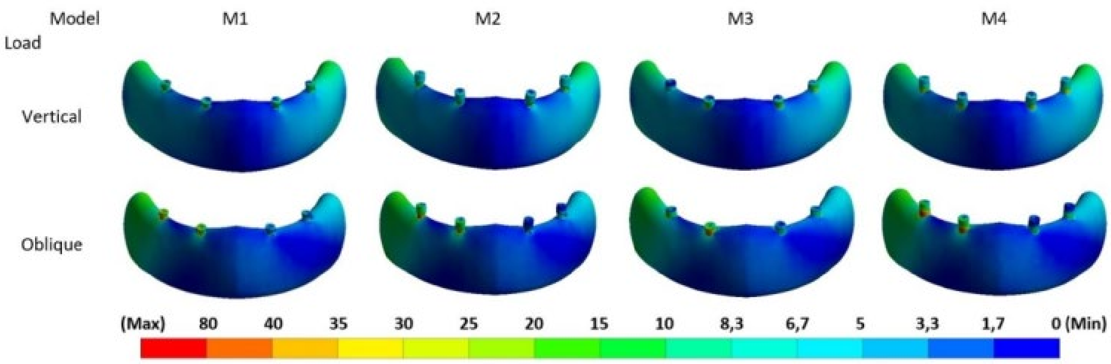


Figure 4 - Von Mises maps of implants/healing caps (unit = MPa)

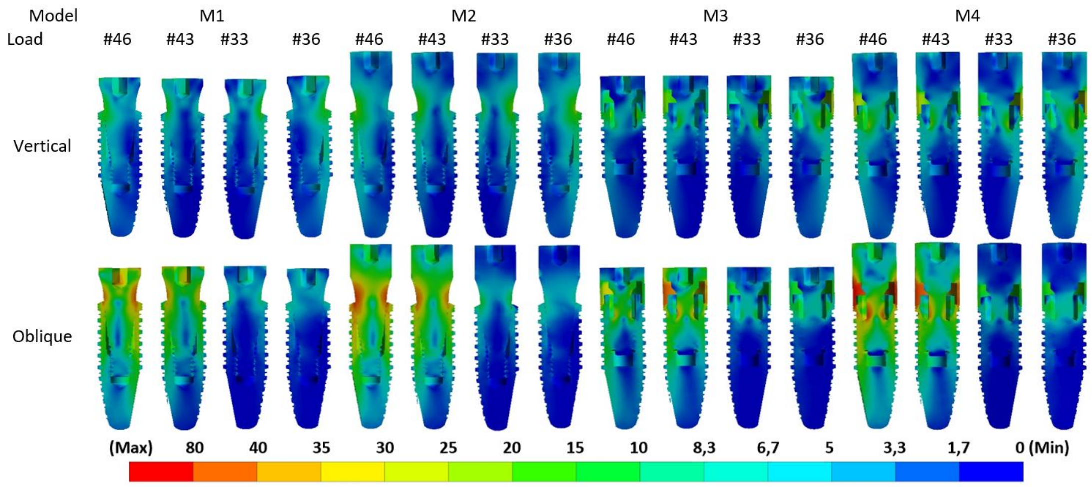
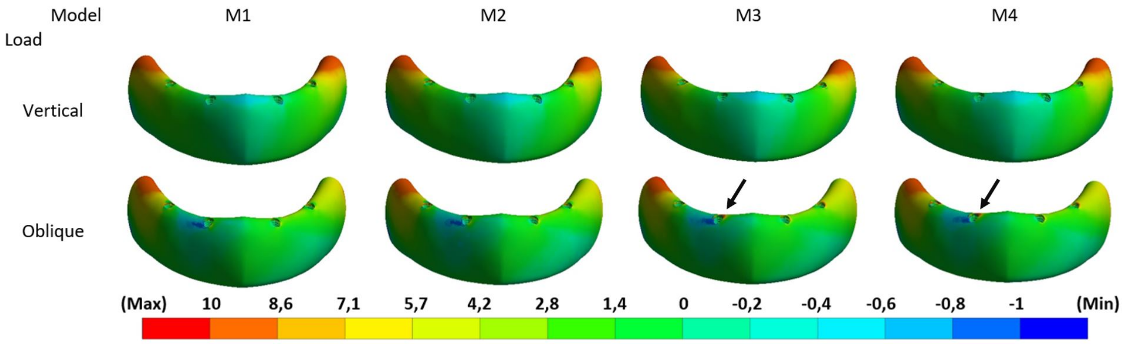


Figure 5 - General Maximum Principal Stress maps of bones (unit = MPa)



Influence of healing caps heights and implant connections on stress distribution in initial osseointegration of implants placed to fabrication of mandibular protocol/overdentures prosthesis. Study by 3D finite element analysis.

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Index Words:	finite element analysis, dental implant, implant abutment, mechanical phenomena, complete denture

Abstract:	Purpose: To evaluate the stress generated on bone tissue, implant, and healing caps while using different heights of caps and different connections in two different loading situations of mandibular overdenture/protocol situation by 3D finite element analysis. Materials and methods: Four 3D models were modeled using scanned image of a laboratory mandibular model and complete denture, including 4 implants placed at crestal level in region of teeth #46, #43, #33 and #36. Type II bone was simulated, separating soft tissue. The implant/healing cap design was obtained from original components. Healing caps of morse taper and external hexagon of 2,5mm and 4,5mm were modeled. 256,2N of vertical (0°) and oblique (45°) loadings were applied over complete denture. Displacement and stress analysis of von Mises and Maximum Principal Stress were performed using ANSYS 19.2. Results: Displacement maps showed no differences and clinically acceptable values for all models. Vertical loading did not show differences on stress distribution varying healing caps or implant connections. Oblique loading showed more stress concentration in healing caps of higher heights and for models using external hexagon implants. Conclusions: According to the results and limitations of this study healing caps of higher heights negatively affect the stress transmission to the supporting structures independently of implant connection and external hexagon implants were more prejudicial to the stress transferring mainly for situations of high heights of healing caps.