

IMPACT OF IMPLANT-RETAINED MANDIBULAR OVERDENTURE ON ORAL MUCOSA - A FINITE ELEMENT ANALYSIS

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ABSTRACT

Aim of the study This study aims to analyze the impact that the mandibular overdenture has on the underlying oral mucosa from the perspective of number of implants used in retention of the overdenture. **Material and methods** A 3D model of a mandible with total edentation was derived from CBCT images, containing cortical and cancellous bone tissue layers. Over the alveolar bone ridge, the oral mucosa was modeled with a 2 mm thickness. The overdenture was retained using 2, 4, 6 and 8 implants in various positions. Loading was applied using muscle forces and boundary conditions that mimic physiological mastication loading. **Results and discussions** Strain and stress values overall increased when using more implants to retain the overdenture. Values exhibited the same pattern in both of the mandibular quadrants. **Conclusions** Although the 2 and 4 IOD led to a decrease of stress and strain levels, it is not necessarily the most favorable option as these also lead to a higher degree of mobility in the overdenture. The aim is to obtain an optimal balance between retention, deformation and displacement of the overdenture and the strain resulted in the soft tissues. There is a need for clinical studies that could determine optimal strain intervals.

Keywords: oral mucosa, overdenture, number of implants, FEA

INTRODUCTION

In total edentulism of the mandible, implant-retained overdentures (IOD) have offered effective oral rehabilitation of the functions of the stomatognathic system [1].

In comparison with conventional dentures, IOD provides higher denture stability, overall better wear comfort, patient satisfaction and improved chewing ability [2,3]. Moreover, studies have reported high success rates for implant survival in overdenture retention making it a long term solution for edentulous patients. [4]. Although IOD presents many benefits, there is still the issue of rotational movement during physiological loading [5].

This motion decreases the mastication ability and also leads to a higher strain on the underlining oral mucosa [6-8]. However, this can be modulated through the design of the overdenture and the number of implants used in retention.

There is no consensus yet regarding the optimal number of implants, although the 2 IOD is considered an adequate solution for mandibular total edentulism [9,10].

Some studies suggest that IOD retained by 3 or 4 implants offer superior retention than 2 IOD [1,6]. Also, while using more than 4 implants does increase the retention, the difference obtained is not significant enough

to justify additional surgical procedures and increased costs [1,6,10].

However, it has been reported that 45% of denture wearers present denture-related mucosal lesions such as frictional keratosis, traumatic ulcer or denture hyperplasia. These types of mucosal lesions are due to excessive movement of the denture which is in close relation to the number of implants used for retention [11,12].

Thus the question is what is the optimal number of implants for IOD to ensure low levels of strain and stress in the underlining mucosa but still have adequate retention for normal mastication. There is little knowledge concerning these aspects and studies have failed to provide a valid consensus.

The scope of our study was to analyze the influence of the number of implants used in retention of overdentures on the underlining oral mucosa, through finite element analysis.

MATERIAL AND METHODS

A 3D model of a human mandible was obtained through software reconstruction using patient-derived Cone Beam Computer Tomography (CBCT) images, as can be seen in Fig.1. This method provided us with an anatomically detailed model to ensure increased accuracy of the results of the finite analysis study. Reconstruction of the human mandible was performed using the Slicer3D software (<http://www.slicer.org>).

Subsequently, further modifications of the model followed to obtain an editable volume, around which to model the other elements of the simulation. The software used was MeshLab version 2016, Autodesk Fusion360 (Autodesk, Inc., San Rafael, CA, USA), and Autodesk Inventor Professional version 2017 (Autodesk, Inc., San Rafael, CA, USA).

The mandibular model obtained has two macro-structures, the outer layer of cortical

bone tissue with a thickness of 2 mm and the inner volume of trabecular bone tissue.

The oral mucosa tissue was modeled with a thickness of 2 mm. To simulate the clinical situation of rehabilitation in total edentulism, implants, overdenture and retaining systems were also modeled (Fig.1).

The software used was Autodesk Fusion360 (Autodesk, Inc., San Rafael, CA, USA) and Autodesk Inventor Professional version 2017 (Autodesk, Inc., San Rafael, CA, USA).

To analyze the impact of the number of implants used in overdenture retention on the underlining oral mucosa, variation of implant number are illustrated in Fig.2 and set as follows:

- 2 implant-supported overdenture;
- 4 implant-supported overdenture;
- 6 implant-supported overdenture;
- 8 implant-supported overdenture;

The retention system used for the overdenture was a locator type system composed of a metal housing, plastic cap, locator abutment, and a standard conical threaded implant, as can be seen in Fig.3.

The simulation of masticatory physiological loading was performed in Simulation Mechanical software version 2017 (Autodesk, Inc., San Rafael, CA, USA).

A static study, with elastic and linear isotropic material properties, was set in the analysis interface.

The materials attributed to the study elements were characterized in the simulation environment by Poisson's coefficient and Young's modulus. The mechanical properties of the materials assigned can be found in Table 1.

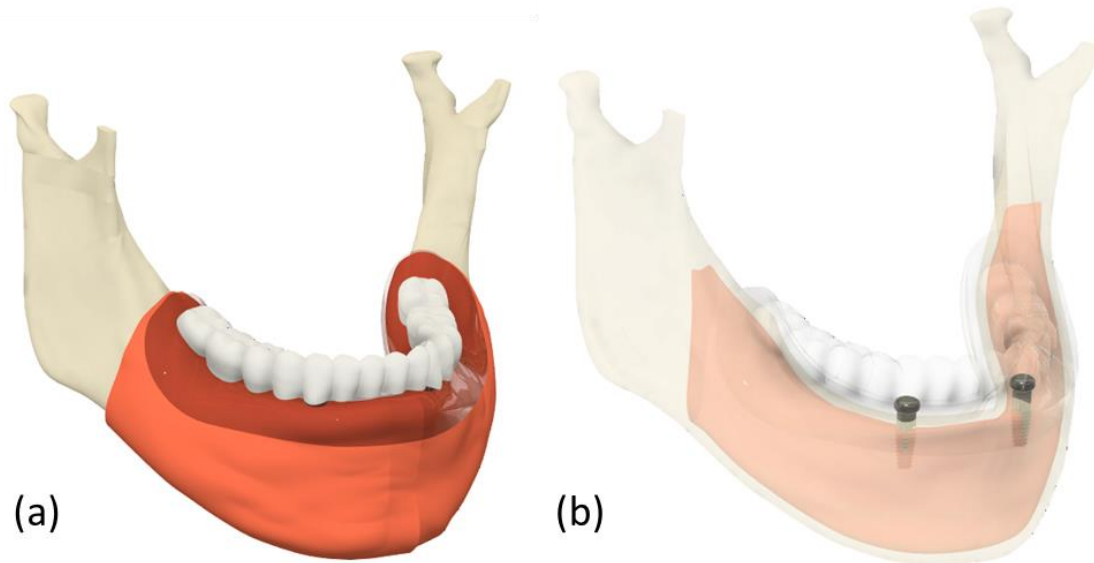


Figure 1. (a) Complete 3D model of the mandible with total edentation and implant-retained overdenture. (b) Transparent view of complete 3D model of the mandible with total edentation and implant-retained overdenture.

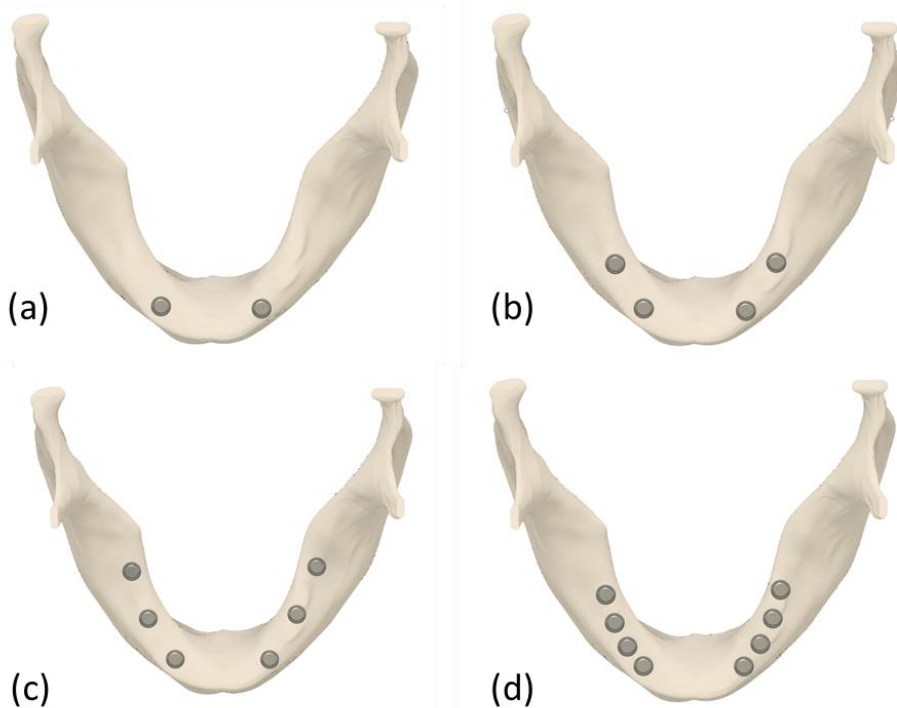


Figure 2. View of implants number and placement on mandible model for overdenture retention. (a) 2 implant retention. (b) 4 implant retention. (c) 6 implant retention. (d) 8 implant retention.

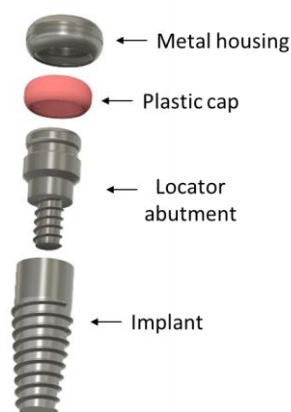


Figure 3. Exploded view of overdenture retention implant system used.

To simulate the anatomical joint of the mandible, the model was fixed at the temporal-mandibular joint surfaces.

Rotation restrictions around the Y and Z axes were applied, allowing for physiological type rotation in the sagittal plane during mastication.

Masticatory type forces corresponding to the pterygoid muscles (P) of 145 N and the masseter muscles (M) of 151 N were applied on the molars and second premolar occlusal surfaces [13].

Table 1. Material properties

| Element | Young's Modulus (MPa) | Poisson coefficient |
|-----------------------|-----------------------|---------------------|
| Cortical bone [14] | 13700 | 0.3 |
| Cancellouse bone [15] | 1370 | 0.3 |
| Gingiva [16] | 19.6 | 0.3 |
| Ti-6Al-4V [17] | 110 000 | 0.35 |
| Acrylic resin [18] | 8300 | 0.28 |
| Nylon [19] | 0.35 | 0.40 |

RESULTS AND DISCUSSIONS

Maximum principal stress and strain were recorded on the adjacent to the overdenture areas of the gingiva. Values obtained for all simulated cases can be found in Fig. 4 and 5.

Strain values overall increased when using more implants to retain the overdenture. This trend is consistent in loading applied in both quadrants. This can be explained by the higher mobility reported in studies when using fewer implants because of the contact between the oral mucosa and the overdenture decreases [1,3,10]. If the overdenture is

restrained by 2 or 4 implants, the degree of mobility increases when masticatory loading is applied. This, in turn, leads to less deformation of the underlining oral mucosa because of the contact between it and the overdenture decreases.

Although the 2 and 4 IOD led to a decrease of the stress and strain levels, this is not necessarily the most favorable option. It is important to note that the overall outcome of an implant-retained overdenture is a balance between stability and strain on the underlining tissues.

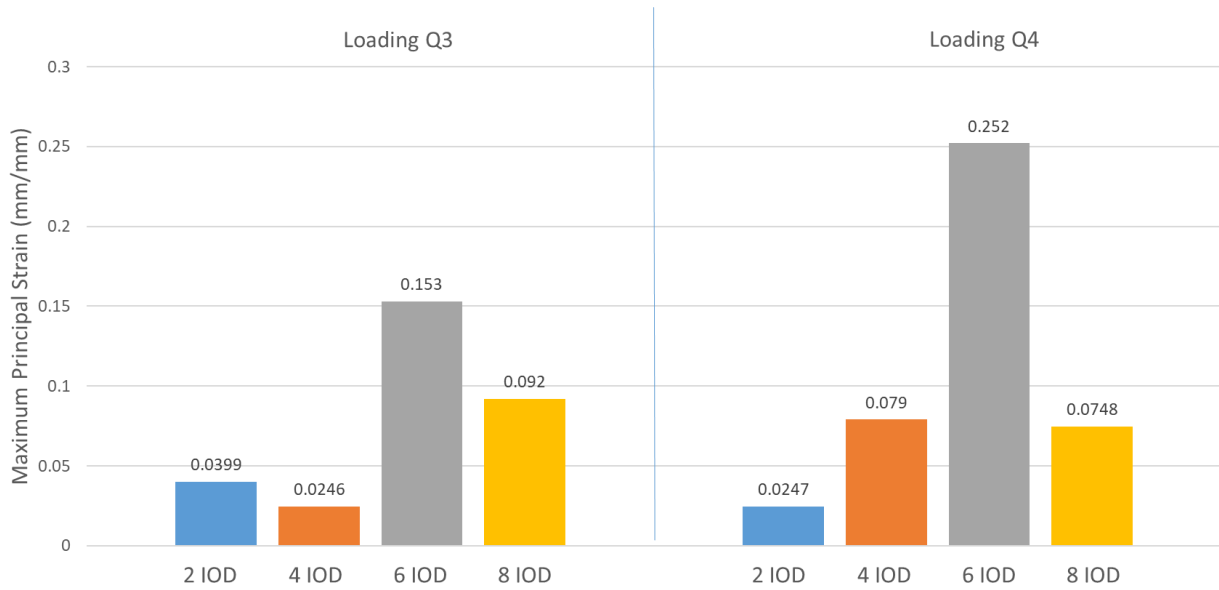


Figure 4. Maximum principal strain recorded in the gingiva when using 2, 4, 6 and 8 implants for retaining the overdenture.

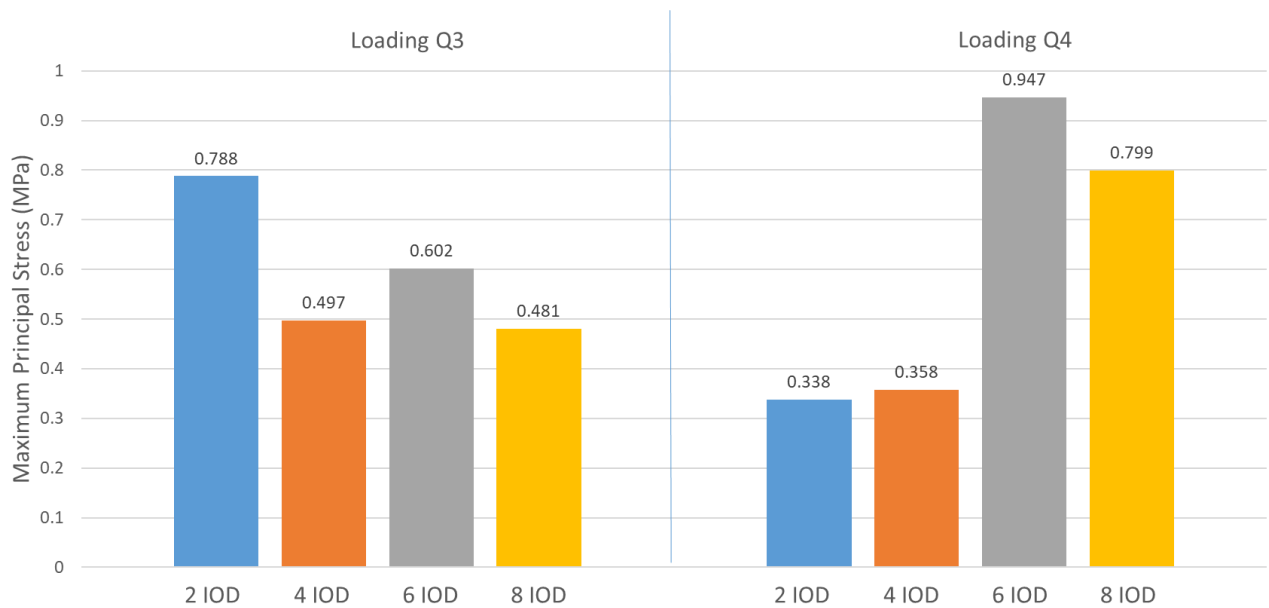


Figure 5. Maximum principal stress recorded in the gingiva when using 2, 4, 6 and 8 implants for retaining the overdenture.

When the patient is chewing or talking and the overdenture is excessively moving, although the strain on the gingiva might be at a low level, there is a large amount of discomfort and stomatognathic functions are affected [10]. In regards to the stress values in oral mucosa when using IOD, there is a limit suggested of

0.2 MPa of pressure on the gingiva for which there are no harmful effects on the mandibular bone [20]. It can be understood that this limit may also represent a threshold for denture-related mucosal lesions but the literature does not specify the extent to which this limit may be used [20]. It is important to note that when

the gingiva is loaded it is subjected to various types of loads not only pressure. However, the results obtained in our study reveal stress values over 0.2 MPa for all simulated cases in loading applied unilaterally in the two quadrants. This suggests that the 0.2 MPa limit is not feasible as it does not represent a reliable parameter to assess the optimal pressure for the oral mucosa.

Kasani et al. reported similar stress values for the mucosa when using 2 and 4 implants [21]. In his study, Kasani analyzed 2, 3, 4 and 5 implant IOD, assessing the stress-induced on the oral mucosa in different types of loading. Kasani reported that increasing the number of implants results in an increase of stress-induced in the mucosa. This is also supported by the results reported by Pileicikiene et al. [22].

The oral mucosa is a complex soft tissue to mathematically describe in finite element analysis. Although the inner mucosa shows resistance to deformation during physiological loading due to its firm attachment to the cortical bone, the surface of the mucosa with no firm support from the bone shows a viscous behavior during loading [22]. There is also the proposed structural model consisting of different tissue layers, each one with correspondent mechanical properties while

also considering the hydraulic movements caused by the blood and lymph [23, 24].

The issue now is to determine the optimal interval of strain to which the underlining oral mucosa can be subjected to. There is a need for clinical studies that could determine such interval and mathematical models to translate such information in concrete parameters.

CONCLUSIONS

1. Strain values overall increased when using more implants to retain the overdenture.

2. Stress increases as the overdenture is retained by more implants.

3. Although the 2 and 4 IOD led to a decrease of stress and strain levels, this is not necessarily the most favorable option as these also lead to a higher degree of mobility in the overdenture.

4. The aim is to obtain an optimal balance between retention, deformation and displacement of the overdenture and the strain resulted in the soft tissues.

5. There is a need for clinical studies that could determine optimal strain intervals and mathematical models to translate such information in concrete parameters.

REFERENCES

- 1 Kutkut A, Bertoli E, Frazer R., et al, A systematic review of studies comparing conventional complete denture and implant retained overdenture. *J Prosthodont Res.* 2018;62:1-9.
- 2 Bakke M, Holm B, Gotfredsen K. Masticatory function and patient satisfaction with implant-supported mandibular overdentures: a prospective 5-year study. *Int J Prosthodont* 2002;15:575–81.
- 3 Fueki K, Kimoto K, Ogawa T, Garrett NR. Effect of implant-supported or retained dentures on masticatory performance: a systematic review. *J Prosthet Dent* 2007;98:470–7.
- 4 Walton JN, Glick N, Macentee MI. A randomized clinical trial comparing patient satisfaction and prosthetic outcomes with mandibular overdentures retained by one or two implants. *Int J Prosthodont* 2009;22:331-9.
- 5 Kimoto S, Pan S, Drolet N, Feine JS. Rotational movements of mandibular two-implant overdentures. *Clin Oral Implants Res* 2009;20:838-43.
- 6 Topkayaa T, Solmaz MY. The effect of implant number and position on the stress behavior of mandibular implant retained overdentures: A three-dimensional finite element analysis. *J Biomech* 2015;48:2102-2109.
- 7 Barão VA, Assunção WG, Tabata LF, et al. Effect of different mucosa thickness and resiliency on

- stress distribution of implant-retained overdentures-2D FEA. *Comput Methods Programs Biomed.* 20;92:213-23.
- 8 Sato H, Kobayashi T, Nomura T et al. Oral mucosa pressure caused by mandibular implant overdenture with different types of attachments. *J Prosthodont Res.* 2019;28:S1883-1958.
 - 9 Thomason JM, Feine J, Exley C, Moynihan P, Müller F, Naert I, et al. Mandibular two implant-supported overdentures as the first choice standard of care for edentulous patients—the York consensus statement. *Br Dent J* 2009;207:185-6.
 - 10 Oda K, Kanazawa M, Takeshita S, et al. Influence of implant number on the movement of mandibular implant overdentures. *J Prosthet Dent.* 2017;117:380-385.
 - 11 Earar K, Negraia MR, Indrei LL, et al. Prosthetic oral rehabilitation in knowledge of pathology of the oral mucosa. *Romanian J Oral Rehab.* 2019;11:200-204.
 - 12 Preoteasa E, Preoteasa CT, Iosif L, et al. Denture and Overdenture Complications, Emerging Trends in Oral Health Sciences and Dentistry, Mandeep Singh Viridi, IntechOpen. 2015 DOI: 10.5772/59250.
 - 13 Correia, A.; Piloto, P.; Reis Campos, J.C.; Vaz, M. Finite element analysis of the mechanical behavior of a partially edentulous mandible as a function of cancellous bone density. *J. Dent. Sci.* 2009, 24, 22–27.
 - 14 Bozkaya, D.; Muftu, S.; Muftu, A. Evaluation of load transfer characteristics of five different implants in compact bone at different load levels by finite elements analysis. *J. Prosthet. Dent.* 2004, 92, 523-530.
 - 15 Chun, H.J.; Park, D.N.; Han, C.H.; Heo, S.J.; Heo, M.S.; Koak, J.Y. Stress distribution in maxillary bone surrounding overdenture implants with different overdenture attachments. *J. Oral. Rehabil.* 2005, 32, 193-205.
 - 16 (Todorovic 2010) gingiva
 - 17 Grandin, H.M.; Berner, S.; Dard, M. A review of titanium zirconium (TiZr) alloys for use in endosseous dental implants. *Materials* 2012;5:1348-1360.
 - 18 Darbar UR, Huggett R, Harrison A, et al. Finite element analysis of stress distribution at the tooth-denture base interface of acrylic resin teeth debonding from the denture base. *J Prosthet Dent.* 1995;74:591-4.
 - 19 Kasani R, Rama Sai Attili BK, Dommeti VK, et al. Stress distribution of overdenture using odd number implants - A Finite Element Study. *J Mech Behav Biomed Mater.* 2019;98:369-382.
 - 20 Kawano F. A study on pressures of supporting tissues under complete denture during functions—concerning the effects of the arrangement of artificial posterior teeth. *J Jpn Prosthodont Soc* 1987;31:726–39.
 - 21 Kasani R, Rama Sai Attili BK, Dommeti VK, et al. Stress distribution of overdenture using odd number implants - A Finite Element Study. *J Mech Behav Biomed Mater.* 2019;98:369-382.
 - 22 Pileicikiene, G., Varpjotas, E., Surna, R. et al. A three-dimensional model of the human masticatory system, including the mandible, the dentition and the temporomandibular joints. *Stomatologija.* 2007;9:27–32.
 - 23 Fleisch L and Austin JC. A histologic study of the response of masticatory and lining mucosa to mechanical loading in the vervet monkey. *J Prosthet Dent* 1978; 39: 211–216.
 - 24 R Kanbara, Y Nakamura, KT Ochiai, T Kawai, Y Tanaka. Three-dimensional finite element stress analysis: the technique and methodology of non-linear property simulation and soft tissue loading behavior for different partial denture designs. *Dental Materials Journal.* 2012;31:297-308.
 - 25 M Saito, Y Miura, K Notani, T Kawasaki. Stress distribution of abutments and base displacement with precision attachment —and telescopic crown - retained removable partial dentures. *Journal of Oral Rehabilitation.* 2003;30:482-487.