BIOMECHANIC STUDY OF IMPLANT-RETANED OVERDENTURE THROUGH 2D-FINITE ELEMENT ANALYSIS

Lucas Fernando Tabata
Department of Dental Materials and Prosthodontics - Araçatuba Dental School - State University of São Paulo (Unesp)
Av. José Bonifácio, n. 1193, Araçatuba, São Paulo, Brazil
lftabata@hotmail.com

Edson A. Capello Sousa
Department of Mechanical Engineering - Faculty of Engineering - State University of São Paulo (Unesp)
Av. Luiz Edmundo Carrijo Coube s/n, Bauru, São Paulo, Brazil
capello@feb.unesp.br

Wirley Gonçalves Assunção
Department of Dental Materials and Prosthodontics - Araçatuba Dental School - State University of São Paulo (Unesp)
Av. José Bonifácio, n. 1193, Araçatuba, São Paulo, Brazil
wirley@foa.unesp.br

Abstract. *The objective of this study was to demonstrated the application of two-dimensional Finite Element Analysis (2D-FEA) to assess stress distribution of implant-retained overdentures prosthesis with two different attachment system. Two models were constructed on software (ANSYS), being: bar-clip group (BCG), edentulous mandible model supporting an overdenture over two implants splinted with bar-clip system and independent o'ring group (IOG), edentulous mandible model supporting an overdenture over two independent implants with o'ring attachments. Evaluation was conducted with 100N loads in central region of the models. Obtained data was grouped and evaluated, and it was possible to observe that BCG (52,086MPa) presented lower values of maximum stress than IOG (78,454MPa) in relation to supporting tissue of the prosthesis, where stress was concentrated in cortical bone of the mandible surrouding implants. It was concluded that bar-clip attachment system, even presenting higher stress concentration on implants and prosthetic components, were more favorable for stress distribution over supporting tissue surrounding implants of implant-retained overdentures.*

Keywords*: dental implant, stress distribution, attachment system, finite element analysis, biomechanics.*

1. INTRODUCTION

The treatment of a fully edentulous mandible by means of implant-retained overdenture has become a routine therapy on dentistry field. Many different attachments available today may be used to support implant-retained overdenture. Currently, mandibular implant-retained overdenture connected with two implants with ball attachments has become a reliable and well-documented treatment (Daas et al., 2007).

Implant-retained overdenture rehabilitation present advantages over conventional complete dentures, especially for mandibular treatment, providing better retention and stability, increasing comfort and masticatory function (Bergendal and Engquist, 1998, Bakke et al., 2002, Awad et al., 2003, MacEntee et al., 2005) with direct influence on self-esteem and quality of life (Kenney and Richards, 1998, Oliveira and Frigerio, 2004, Heydecke et al., 2005). These characteristics associated with high success rate of implant therapy (Adell et al., 1981), suggest the mandibular two implant overdenture as the first treatment option for edentulism (Feine et al., 2002).

Although, even with high success rate, surrounding implant cortical bone loss has been registered, being one of the principal failure causes. Biomechanical evaluation suggests that the most important factor for this cortical bone resorption is related to an overload of the implants (Branemark et al., 1977). The excess of functional loads, generate stress that are dissipated from attachment system to implants and supporting tissue, and the intensity and amplitude of bone resorption is determined by the mechanisms of stress transmission and distribution of each attachment system (Misch, 2000).

For a favorable prognosis it is necessary a correct selection of attachment system, based not only on retention or cost aspects, but principally in biomechanics factors, once it is the most fragile link between prosthesis and implant (Watson, 2001).

Clinically it is still not possible to assess stress/strain distribution of implant-retained overdentures at bone level, only at abutment level through strain gauges analysis (Mericske-Stern, 1997, Tokuhisa et al., 2003). However, there are others methods based on simulation, as photoelastic method (Frederick and Caputo, 1996, Kenney and Richards, 1998, Fanusco and Caputo, 2004) and finite element analysis (FEA) (Meijer et al, 1992, Mennicucci et al., 1998, Chun et al., 2005), that allow better understanding of stress distribution via implants to supporting tissue (Sahin et al., 2002).

Bioengineering studies have been important in the understanding of biomechanical behavior of osseointegrated implants and its prosthesis (Chao et al., 1995) and because the components in a dental implant-bone system are extremely complex geometrically, FEA has been viewed as the most suitable tool for analyzing those (Geng et al., 2001).

O overdentures treatment mechanisms of stress distribution of attachment systems are inconclusive in literature (Fanusco and Caputo, 2004), so the main goal of the present study was to analyze the influence of attachment system on stress distribution in supporting tissue surrounding implants of mandibular implant-retained overdentures using a two-dimensional finite element analysis (FEA-2D), induced by a central functional load.

2. MATERIALS AND METHOD

For problems involving complicated geometries, it is very difficult to achieve an analytical solution. Therefore, the use of numerical methods such FEA is required. FEA is a technique for obtaining a solution to a complex mechanical problem by dividing the problem domain into a collection of much smaller and simpler domains (elements) in which the field variables can be interpolated with the use of shape functions. An overall approximated solution to an original problem is determined based on variation principles. In others words, FEA is a method whereby, instead of seeking a solution function for the entire domain, one formulates the solution functions for each finite element and combines them properly to obtain the solution to the whole body (Geng et al., 2001).

With this purpose, two-dimensional finite elements models were designed as a frontal section of anterior portion of an edentulous mandible bone for two situations: bar-clip group (BCG), edentulous mandible model supporting an overdenture over two splinted implants with bar-clip system; and independent o'ring group (IOG), edentulous mandible model supporting an overdenture over two independent implants with o'ring abutments. Mucosa, denture base, artificial teeth, implants and prosthetic components (attachment system) were also represented in all models.

For construction of the models, the contour of the denture was obtained from a frontal photographic image of demonstration model of a mandibular complete denture and imported into image analysis software (AutoCAD 2005, AutoDesk Inc., San Rafael, CA, USA). The mucosa and cortical bone of the mandible were reproduced as a 1-mm and 0.5-mm layer respectively. Trabecular bone of the mandible was reproduced as a 20-mm layer in which, two dental implants of 3.75mm in diameter and 11.5mm in length (Master Screw, Conexão Sistemas de Prótese Ltd, São Paulo, SP, Brazil) were positioned.

Bar-clip attachment system is characterized as a supra-structure connected directly to implants and cast in NiCr alloy (Neochron, CNG Soluções Protéticas, São Paulo, SP, Brazil), according to standard laboratory procedures based on plastic UCLA cylinders (055021, Conexão Sistemas de Prótese Ltd, São Paulo, SP, Brazil) and plastic bar (204000, Conexão Sistemas de Prótese Ltd, São Paulo, SP, Brazil). Retention of this attachment system is done by connection of a plastic clip (204000, Conexão Sistemas de Prótese Ltd, São Paulo, SP, Brazil) to the supra-structure bar "Fig 1".

O'ring attachment system (049071, Conexão Sistemas de Prótese Ltd, São Paulo, SP, Brazil) is characterized by two pre-manufactured components system (male and female) whereas the retention is promoted by the rubber ring inside the capsule (female component) that takes place over the ball shaped component (male component) "Fig. 2".

Figure 1. Bar-clip attachment system connected with two implants and embedded in a self-curing acrylic resin.

Figure 2. O'ring attachment system connected to an implant and embedded in a self-curing acrylic resin.

For reproduction of attachment systems in the models, each implant-attachment system complex was embedded in a self-curing acrylic resin (Jet, Artigos Odontológicos Clássico Ltd, São Paulo, SP, Brazil) using an embedding machine (Arotec PRE 30S, Arotec S.A. Ind. e Com., Cotia, SP, Brazil). Both implant-attachment sets were sectioned on longitudinal axis using a saw machine (Isomet 1000 Precision Saw, Buehler, Lake Bluff, II, USA) and then digitalized on a scanner (HP scanjet 2400, Hewlett-Packard Company, Palo Alto, CA, USA). The scanned images were imported into image analysis software and placed within the supporting tissue and overdenture.

The outline of the models images was manually quoted and each point converted into *x* and *y* coordinates. The coordinates were finally imported into the finite element software (Ansys 7, Swanson Analysis System, Houston, Pa, USA) as keypoints of definitive images.

Ten different types of materials were assigned for two models: acrylic tooth, acrylic resin, mucosa, cortical bone, trabecular bone, titanium alloy, Ni-Cr alloy, stainless steel, plastic clip and o'ring rubber. Each object was then subdivided in smaller elements. The elements shapes were 2-D six-node triangular plain stress element (plane 2). The final models had a total number of 8210 elements and 17228 nodes for the BCG "Fig. 3" and 9206 elements and 19016 nodes for the IOG "Fig. 4".

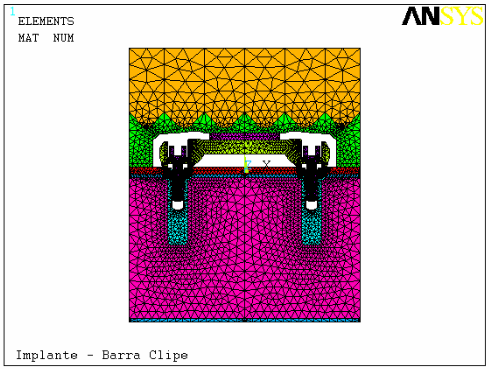

Figure 3. Finite element mesh of edentulous mandible model supporting an overdenture over two splinted implants connected with the bar-clip system (BCG) (8210 elements and 17228 nodes)

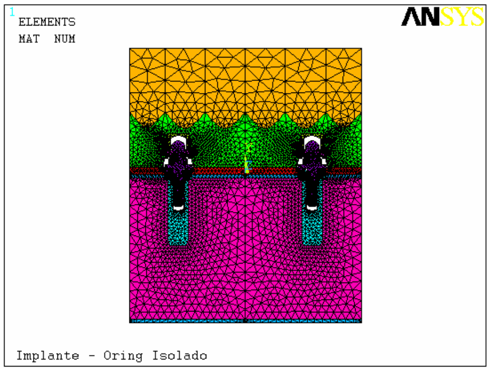

Figure 4. Finite element mesh of edentulous mandible model supporting an overdenture over two unsplinted implants with the O'ring system (IOG) (9206 elements and 19016 nodes)

Certain assumptions need to be made to make the modeling and solving process possible (Geng et al., 2001). Mechanical properties of cortical bone, trabecular bone, mucosa and the other materials used in the analysis were assumed to be homogeneous, isotropic and linearly elastic as used in other FEA studies of Meijer et al., 1992, Mennicucci et al., 1998, Chun et al., 2005. For further studies, the use of different properties characteristics, as considering anisotropic the supporting tissues is suggest to simulate more realistic conditions. The materials properties used in the FEA-2D are shown in "Tab. 1".

Table 1. Mechanical properties of materials

Materials	**Young's modulous (MPa)**	**Poisson's ratio (v)**	**Reference**
Acrylic tooth	8300	0,28	(28)
Acrylic resin	8300	0,28	(28)
Mucosa	680	0,45	(29)
Cortical bone	13700	0,3	(20)
Trabecular bone	1370	0,3	(20)
Implant (Ti-6Al-4V)	103400	0,35	(30)
Ni-Cr alloy	24900	0,32	(31)
Stainless Steel	19000	0,31	Manufacture*
Plastic clip	3000	0,28	Manufacture*
O'ring rubber	5	0,45	(22)

* Personal communication

The boundaries conditions of the supporting tissue were constrained in the *x* axis and symmetric prescribed in the *y* axis, so as to simulate the physiological conditions of the clinical situation. Axial loads of 100 N (Meijer et al., 1992) were applied either on incisal surface of both central incisor teeth in each model.

First principal stresses of the models were assessed numerically and color-coded and compared among the models.

3. RESULTS

Evaluation of the stress maps “Fig. 5 and 6” was conducted through a plotting procedure of the models, utilizing Ansys software that provided individual maps for each model structure (prosthesis, mucosa, cortical bone, trabecular bone and implant plus prosthetic components) “Fig. 7 and 8”. This procedure allowed easier stress concentration location at the structures and stress distribution comparison between studied groups, because the high value difference of maximal and minimal stress of principal stress maps. Also, values of maximum and minimum stress of both groups for principal maps “Tab. 2” and plotted maps “Tab. 3” were inserted into tables for better comprehension of obtained data.

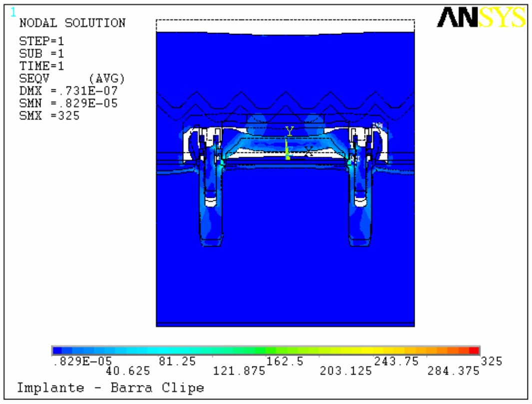

Figure 5. Stress map of bar-clip attachment system (BCG) under central loading of 100N

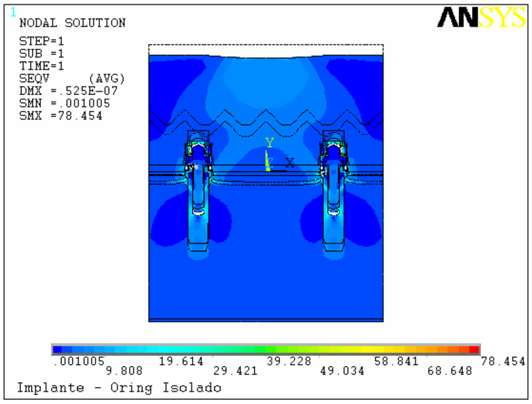

Figure 6. Stress map of independent O’ring attachment system (IOG) under central loading of 100N

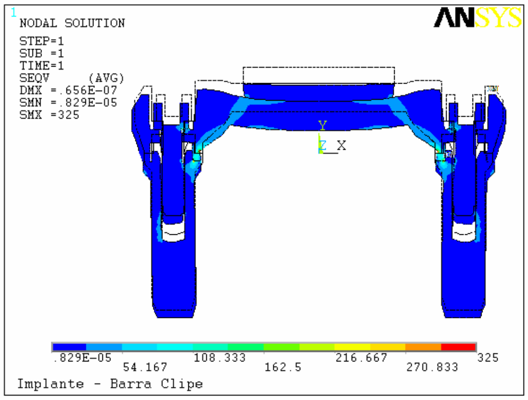

Figure 7. Plotted map of implants and prosthetic components of bar-clip attachment system

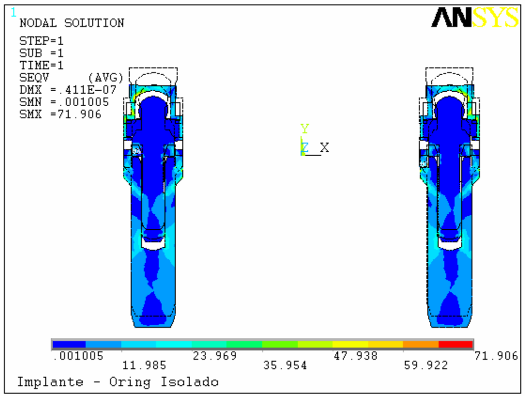

Figure 8. Plotted map of implants and prosthetic components of independent O’ring attachment system

Table 2. Maximal and minimal stress values (MPa) and location for BC and IO groups under central loading.

Stress Maps (MPa)				
Group	**Maximal stress**	**Location**	**Minimal stress**	**Location**
BCG	325.0	Bar-implant interface	~0	Bar distal end
IOG	80.0	Cortical bone surrounding implant	~0	Implant prosthetic platform

Table 3. Comparison between BCG and IOG according to stress values (MPa) and location on prosthesis, supporting tissue, implants and prosthetic components under central loading.

Plotted structure	**Group**	
	BCG	**IOG**

Overdenture	(7.1-10.6) inferior central incisor incisal surface	(5.1-9.9) inferior central incisor incisal surface
	(21.1) mucosa interface	(29.1) mucosa interface
Mucosa	(16.3) surrounding implant	(17.7) surrounding implant
Cortical bone	(52.0) surrounding implant	(78.4) surrounding implant
Trabecular bone	(7.3) implant apical region	(5.9) implant apical region
	(5.1) under inferior canine area	(5.0) under inferior canine area
Implants	(263.5) bar-implant interface	(71.9) abutment-implant interface
Prosthetic components	(325.0) bar-implant interface	(71.9) abutment-implant interface

3. DISCUSSION

FEA has been extensively used in the prediction of biomechanical performance of dental implants systems (Geng et al., 2001) however, any study based on model simulation must to be understood under the conditions of its own methodology, with its advantages and disadvantages (Fanusco and Caputo, 2004). This study utilized 2D-FEA to assess the influence of attachment system on stress distribution of implant-retained overdentures. Although the stress maps were obtained in 2-dimensional plan which limited the full reproduction of a third axis of stress distribution, these do not invalidate the obtained data that are correlated with significant studies present in literature (Meijer et al., 1992, Chao et al., 1995, Mennicucci et al., 1998, Chun et al., 2005).

It was verified from principal maps obtained of FE analysis that stress concentration was located on around implant, principally around implant neck in cortical bone. Studies (Meijer et al., 1992, Chao et al., 1995, Mennicucci et al., 1998, Chun et al., 2005) verified that maximum stress is concentrated at cortical bone surrounding implants, probably due to higher elastic modulus of cortical bone compared with that trabecular bone.

Bar-clip attachment system mechanical function differs from o'ring attachment. While bar-clip system is associated with two implants and provide only antero-posterior rotation movement for prosthesis, independent o'ring attachment system allow antero-posterior, lateral and intrusive movement of the prosthesis, which allowed greater amplitude movement. Based on this information, it can be explained the higher stress concentration presented by IOG, on supporting tissue (especially cortical bone and mucosa) surrounding implants when compared to BCG. Most likely, the intrusive movement of prosthesis causes compression of the supporting tissue that increased the observed stress values for IOG.

Cortical bone stress concentration is a clinical concern, due to peri-implant bone resorption and is also correlated in literature (Meijer et al., 1992, Chao et al., 1995, Mennicucci et al., 1998, Chun et al., 2005). According to these studies cortical bone stress surrounding independent implants associated with o'ring attachment was justified by the absence of implants splinting, which allow greater implant movement increasing stress at implant neck interface with cortical bone.

For implants and prosthetic components BCG presented higher stress concentration than IOG "Tab. 3", however, despite the minor difference in stress distribution on trabecular bone, and even not presenting biomechanics improvement on stress distribution for implants and prosthetic components, BCG shown better stress distribution over mucosa and cortical bone, which is correlated with a prospective clinical study of Bergendal and Engquist (1998) that showed more implant loss with ball (o'ring) retained overdentures (38,8%) than with bar-clip retained overdentures (20,6%).

The data in the present study is not in agreement with others FE studies (Meijer et al., 1992, Chun et al., 2005), photoelastic methods (Frederick and Caputo, 1996, Kenney and Richards, 1998) and strain-gauges analysis (Tokuhisa et al., 2003) that assessed stress distribution of implant-retained overdentures on supporting tissue, in relation to attachment system. These studies stated that independent implants associated with o'ring attachments optimized stress distribution.

This study differs from those studies that used photoelastic and strain-gauges methods because individual comparison analysis of supporting structures (mucosa, cortical bone and trabecular bone). Photoelastic method utilizes one specific photoelastic resin to represent both cortical and trabecular bone, and simulates mucosa usually with impression material that does not present photoelastic properties. Strain-gauges only allow abutment level strain analysis. Difference was also present in comparison to others FEA studies (Meijer et al., 1992, Chun et al., 2005) that applied loads directly over abutments and implants, without the simulation of prosthesis device, as presented in this study.

Mechanical analysis of the data suggests that the increased stress concentration on implants and prosthetic components of bar-clip attachment promote a relief of stress concentration on supporting tissue. Clinically, this situation is more interesting for favorable prognosis of the prosthetic treatment than the relief of stress concentration on implants and prosthetic components that would increase stress on cortical bone area surrounding implants leading to bone resorption and failure of the prosthetic rehabilitation.

Biological consequences of stress induced in the bone supporting the implants by attachment design are controversial, and there is no empirical evidence that any particular attachment design is superior to the other as well as overall satisfaction (MacEntee et al., 2005). Nonetheless stress distribution is an important factor when rehabilitating patients with implant prosthetic treatment (Chun et al., 2005), so it is desirable a attachment system that promote equitable load transfer, to prevent bone resorption and increase treatment favorable prognosis.

5. CONCLUSION

Based on the results and within the limitation of this study, it is possible to conclude that:

- FEA has been used as a successfully bioengineering tool in the prediction of biomechanical performance of dental implants systems.
- Attachment systems of implant-retained overdentures produce different characteristics of stress distribution that were concentrated at cortical bone surrounding implants.
- Independent o’ring attachment system induced higher stress concentration than bar-clip system on supporting tissue.
- In relation to stress distribution, bar-clip attachment system optmized load transfer.

6. REFERENCES

Adell, R., Lekholm, U., Rockler, B., Branemark, P-I., 1981, “A 15-year study of osseointegrated implants in the treatment of the edentulous jaw”, International Journal of Oral Maxillofacial Surgery, Vol.10, No. 6, pp. 387-416.

Awad, M.A., Lund, J.P., Dufresne, E. and Feine. J.S., 2003, “Comparing the efficacy of mandibular implant-retained overdentures and conventional dentures among middle-aged edentulous patients: satisfaction and functional assessment”, .International Journal Prosthodontics, Vol. 16, No. 2, pp. 117-122.

Bakke, M., Holm, B. and Gotfredsen K., 2002, “Masticatory function and patient satisfaction with implant-supported mandibular overdentures: a prospective 5-year study”, International Journal Prosthodontics, Vol. 15, No. 6, pp. 575-581.

Bergendal, T. and Engquist B., 1998, “Implant-supported overdentures: a longitudinal prospective study”, International Journal Oral Maxillofacial Implants, Vol. 13, No. 2, pp. 253-262.

Branemark, P-I, Hanson, B.O., Adell, R., Breine, U., Lindstron, J., Hallen, O., Ohman, A., 1977, “Osseointegrated implants in the treatment of the edentulous jaw: Experience from a 10-year period”, Scandinavian Journal of Plastic Reconstructive Surgery. Supplementum, Vol.16, pp.1-132.

Chao, Y.L., Meijer, H.J., Van Oort, R.P., Versteegh, P.A.M., 1995, “The imcomprehensible success of the implant stabilized overdenture in the edentulous mandible: a literature review on transfer of chewing forces to bone surrounding implants”, European Journal of Prosthodontics and Restorative Dentistry, Vol.3, No. 6, pp. 255-261.

Chun, H.G., Park, D.N., Han, C.H., Heo, S.J., Heo, M.S., Koak, J.Y., 2005, “Stress distribution in maxillary bone surrounding overdenture implants with different overdenture attachments”, Journal of Oral Rehabilitation, Vol.32, No. 3, pp. 193-205.

Daas, M., Dubois, G., Bonnet, A.S., Lipinski, P., Rignon-Bret, C., 2007, “A complete finite element model of a mandibular implant-retained overdenture with two implants: comparison between rigid and resilient attachment configurations”, Medical Engineering and Physics, doi: <http://10.1016/j.medengphy.2007.02.005>,

Fanuscu, M.I., Caputo, A.A., 2004, “Influence of attachments systems on load transfer of an implant-assisted maxillary overdenture”, Journal of Prosthodontics, Vol. 13, No. 4, pp. 214-220.

Feine, J.S., Carlsson, G.E., Awad, M.A., Chechade, A., Duncan, W.J., Gizani, S. et al., 2002, “The McGill consensus statement on overdentures. Mandibular two-implant overdentures as first choice standard of care for edentulous patient”, International Journal of Oral Maxillofacial Implants, Vol.19, No. 1, pp. 3-4.

Fitzpatrick, B., 2006, “Standard of care for the edentulous mandible”, Journal of Prosthetic Dentistry, Vol. 95, No x, pp. 71-78.

Frederick, D.R., Caputo, A.A., 1996, “Effects of overdenture retention designs and implant orientations on load transfer characteristics”, Journal of Prosthetic Dentistry, Vol.76, No. 6, pp. 624-632.

Freeman, C., Brook, I. and Joshi, R., 2001, “Long term follow-up of implant-stabilized overdentures”, European Journal Prosthodontics Restorative Dentistry, Vol. 9, No. 3-4, pp. 147-150.

Geng, J.P., Tan, K.B.C., Liu, G.R., 2001, “Application of finite element analysis in implant dentistry: A review of literature”, Journal of Prosthetic Dentistry, Vol. 85, No.6, pp. 585-598.

Heydecke, G., Thomason, J.M., Lund J.P. and Feine, J.S., 2005, “The impact of conventional and implant supported prostheses on social and sexual activities in edentulous adults. Results from a randomized trial 2 months after treatment”, Journal of Dentistry , Vol. 33, No. 8, pp. 649-657.

Kenney, R. and Richards, M.W., 1998, “Photoelastic stress patterns produced by implant-retained overdentures”, Journal of Prosthetic Dentistry, Vol. 80, No. 5, pp. 559-564.

MacEntee, M.I., Walton, J.N. and Glick, N., 2005, “A clinical trial of patient satisfaction and prosthodontic needs with ball and bar attachments for implant-retained complete overdentures: three-year results”, Journal of Prosthetic Dentistry, Vol. 93, No. 1, pp. 28-37.

Meijer, H.J., Kuiper, J.H., Starmans, F.J.M., Bosman, F., 1992, “Stress distribution around dental implants: influence of superstructure, length of implants and height of mandible”, Journal of Prosthetic Dentistry, Vol. 68, No. 1, pp. 96-102.

Menicucci, G., Lorenzetti, M., Oera, P., Preti, G., 1998, “Mandibular implant-retained overdenture: finite element analysis of two anchorage systems”, International Journal of Oral Maxillofacial Implants, Vol.13, No. 3, pp. 369-376.

Mericske-Stern, R., 1997, “Force distribution on implants supporting overdentures: the effect of distal bar extensions: a 3-D in vivo study”, Clinical Oral Implant Research, Vol.8, No. 7, pp. 142-151.

Misch, C.E., 2000, “Implantes Dentários Contemporâneos”, Ed. Santos, São Paulo, Brazil, 685p.

Oliveira, T.R.C. and Frigerio, M.L.M.A., 2004, “Association between nutrition and the prosthetic condition in edentulous elderly”, Gerodontology, Vol. 21, No. 4, pp. 205-208.

Sahin, S., Çehreli, M.C., Yalçin, E., 2002, “The influence of functional forces on the biomechanics of implant-supported prosthesis – a review”, Journal of Dentistry, Vol.30, No. 7-8, pp. 7-8.

Spiekermann, H., 2000, “Implantologia”, Ed. Artmed, Porto Alegre, Brazil, 288p.

Tokuhisa, M., Matsushita, Y., Koyano, K., 2003, “In vitro study of mandibular implant overdenture retained with ball, magnet, or bar attachments: comparison of load transfer and denture stability”, International Journal of Prosthodontics, Vol.16, No. 2, pp. 128-134.

Watson C.J, Tinsley D., Sharma S., 2001, “Implant complication and failures: the complete overdenture”, Dental Update, Vol.28, No. 5, pp. 234-240.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.