AMERICAN COLLEGE OF PROSTHODONTISTS

Effects of Horizontal Misfit and Bar Framework Material on the Stress Distribution of an Overdenture-Retaining Bar System: A 3D Finite Element Analysis

Aloísio O. Spazzin, DDS,[1,2] Mateus Bertolini Fernandes dos Santos, DDS, PhD,[2] Lourenço Correr Sobrinho, DDS, MSc, PhD,[3] Rafael Leonardo X. Consani, DDS, PhD,[2] & Marcelo F. Mesquita, DDS, PhD[2]

[1]Department of Prosthodontics, Dental School, Meridional Faculty (IMED), Passo Fundo, RS, Brazil
[2]Department of Prosthodontics and Periodontics, Piracicaba Dental School, State University of Campinas, Piracicaba, Brazil
[3]Department of Restorative Dentistry, Dental Materials Division, Piracicaba Dental School, State University of Campinas, Piracicaba, Brazil

Keywords
Implant prosthesis; bar material; fit; stress; finite element analysis.

Correspondence
Aloísio Oro Spazzin, Senador Pinheiro St., 304, Cruzeiro, 99070-220, Passo Fundo, RS, Brazil. E-mail: aospazzin@yahoo.com.br

Accepted November 29, 2010

doi: 10.1111/j.1532-849X.2011.00759.x

Abstract

Purpose: To evaluate the influence of horizontal misfit change and bar framework material on the distribution of static stresses in an overdenture-retaining bar system using finite element (FE) analysis.
Materials and Methods: A 3D FE model was created including two titanium implants and a bar framework placed in the anterior part of a severely resorbed jaw. The model set was exported to mechanical simulation software, where horizontal displacement (10, 50, 100, and 200 μm) was applied simulating the settling of the framework, which suffered shrinkage during laboratory procedures. Four bar materials (gold alloy, silver–palladium alloy, commercially pure titanium, and cobalt–chromium alloy) were also simulated in the analysis using 50 μm as the horizontal misfit. Data were qualitatively evaluated using von Mises stress, given by the software.
Results: The misfit amplification presented a great increase in the stress levels in the inferior region of the bar, screw-retaining neck, cervical and medium third of the implant, and cortical bone tissue surrounding the implant. The higher stiffness of the bar presented a considerable increase in the stress levels in the bar framework only.
Conclusion: The levels of static stresses seem to be closely linked with horizontal misfit, such that its amplification caused increased levels of stress in the structures of the overdenture-retaining bar system. On the other hand, the stiffness of the bar framework presented a lower effect on the static stress levels.

Overdentures retained by two implants can be attached using different systems. O-ring attachments allow the prosthesis to rotate in all directions.[1] Sometimes, however, the inclination of the implants may preclude the use of these attachments. Another possibility is to use resilient attachments to attach the denture to a rigid bar assembly that interconnects with the osseointegrated implants.[2] When this system is chosen, a passive fit between the bar framework and the implants is required for a successful restoration.[3,4] The major difference to teeth is that osseointegrated implants do not have the resiliency of the periodontal membrane found in natural dentition.[5,6] Therefore, the implants are unable to fit to the misfits.

Potential distortion can be created at any step of the implant prosthesis fabrication process. The error is due primarily to the volumetric inconsistency and linear expansion of the fabrication materials used.[7–9] When there is a poor fit between structures, tensile, compressive, and bending forces may be introduced into an implant-retained restoration and may result in failure of the components.[4,10,11] In addition, a poor fitting framework may also transfer unwelcome stress to the bone/implant interface, which could induce a loss of osseointegration.[12,13] However, some studies have found that dental implants tolerate certain levels of misfit.[14,15]

Today, it is difficult to determine these states due to the limitations of these studies and ethical principles involved in in vivo studies. Numerical analysis can help overcome the limitations of traditional experimental methods by offering accurate and reliable information about the biomechanical efficiency of multiple implant prostheses with regard to bar framework, implant, and bone response.[16]

A recent study[17] using finite element analysis (FEA) showed that the amplification of vertical misfits increased the concentration of static stress in the mechanical part of an overdenture-retaining bar system; however, this increase was not considerable in the periimplant bone tissue. Little is known about the influence of horizontal misfit in static stress distribution in implant prostheses.

Another important factor for which there is still limited data is the effect of the stiffness of the bar material. Several alloys and metals have been used to make prosthetic frameworks. The first implant-supported frameworks, fabricated of gold alloy, began to be used in oral rehabilitations in the early 1970s.[18] Nevertheless, the high cost of noble alloys led to a search for alternative alloys. A study evaluated the effect of four framework materials on the stress distribution in a six-implant-supported fixed denture and periimplant bone tissue.[16] However, the authors did not consider the misfits present in implant dentures.

The aim of this study was to evaluate, using 3D FEA, the influence of: (1) level of horizontal misfit (10, 50, 100, 200 μm); and (2) bar materials [type IV gold alloy (Au), silver–palladium alloy (Ag–Pd), commercially pure titanium (Ti), and cobalt–chromium alloy (Co–Cr)] with 50 μm of horizontal misfit on the distribution of static stresses in an overdenture-retaining bar system. The two hypotheses tested were that: (1) the amplification of the horizontal misfit increases the levels of static stresses in mechanical and biological parts of the system; and (2) the higher stiffness of the bar material increases the levels of static stresses in mechanical and biological parts of the system when a horizontal misfit is present.

Materials and methods

Geometric model

The 3D model was defined starting from clinical data taken from a common situation. The anterior part of a severely resorbed jaw and an overdenture-retaining bar system above two osseointegrated implants were modeled using a 3D parametric solid modeler (Rhinoceros 3.0 software; McNeel, Seattle, WA). The geometry of the modeled jaw portion was obtained starting from computed tomography data with type III bone.[8] Two 3.75-mm diameter × 10-mm length Ti implants (Nobel Biocare, Yorba Linda, CA), with external hexagon, were selected. A circular bar (2 mm diameter) and two UCLAs of an overdenture-retaining bar system were also modeled, with an 18.5-mm distance between the UCLA centers.

Finite element model

The finite element (FE) model was obtained by importing the solid model into mechanical simulation software (NEiNastran 9.0; Noran Engineering Inc., Westminster, CA) using the STEP (*.stp) format. The corresponding elastic properties, such as Young's modulus and Poisson ratio, were determined from values obtained from the literature[17,19–23] (Table 1).

The following assumptions were made. All materials were presumed to be linear elastic, homogenous, and isotropic.[24] The implant thread and cancellous and cortical bone were removed because after several convergence tests, they were found to be irrelevant to the analysis and provided a relevant reduction in elements. Complete adhesion was considered between bone and implant and bar and implant provided by osseointegration and preload of the screw, respectively. Screw and implant were considered a single structure because this assumption was irrelevant for the purpose of the analysis. The model stability was carried out to obtain a reliable model, which was regarded as relevant to engineering and clinical aspects.

Table 1 Material properties

Material	Young's modulus (GPa)	Poisson's ratio (v)
Cortical bone[19]	13.7	0.3
Cancellous bone[19]	1.37	0.3
Titanium (implant)[21]	110	0.33
Titanium (screw)[20]	110	0.28
Type IV gold alloy[23]	80	0.33
Silver–palladium alloy[22]	95	0.33
Commercially pure titanium[20]	110	0.28
Cobalt–chromium[22]	218	0.33

A 3D FE model was constructed using a tetrahedral element, with ten nodes. The volumes were redefined in the new environment and meshed, finally resulting in a model with 13,272 elements and 15,152 nodes. All nodes on the bone's external surface were constrained in all directions to allow application of the displacement condition and stresses to be created in the models.

Two FEAs were carried out separately. For horizontal misfit effect, four models were created with different levels of horizontal misfit (10, 50, 100, 200 μm) between bar and implant, using Au as the bar material: Au/10, Au/50, Au/100, and Au/200. For bar-material effect, four models were created using different bar materials (Au, Ti, Ag–Pd, Co–Cr) with 50 μm horizontal misfit between bar and implant: Au/50, AgPd/50, Ti/50, and CoCr/50.

The displacements were applied on the bar end to simulate the elimination of the horizontal misfit through tightening of the retaining screws. The misfits simulate a condition of linear distortion that could be created by contraction during the fabrication process, reducing the bar length (Fig 1). Model stability was again checked, and particular attention was paid to the refinement of the mesh at the bone/implant interface. The results of the FEA were represented by figures and color gradients of stresses and presented in terms of the von Mises stress values because a higher von Mises stress is a strong indication of a greater possibility of failure.

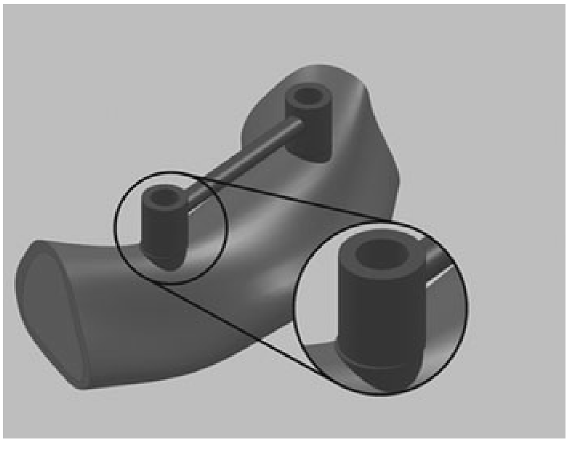

Figure 1 Design of the geometric model.

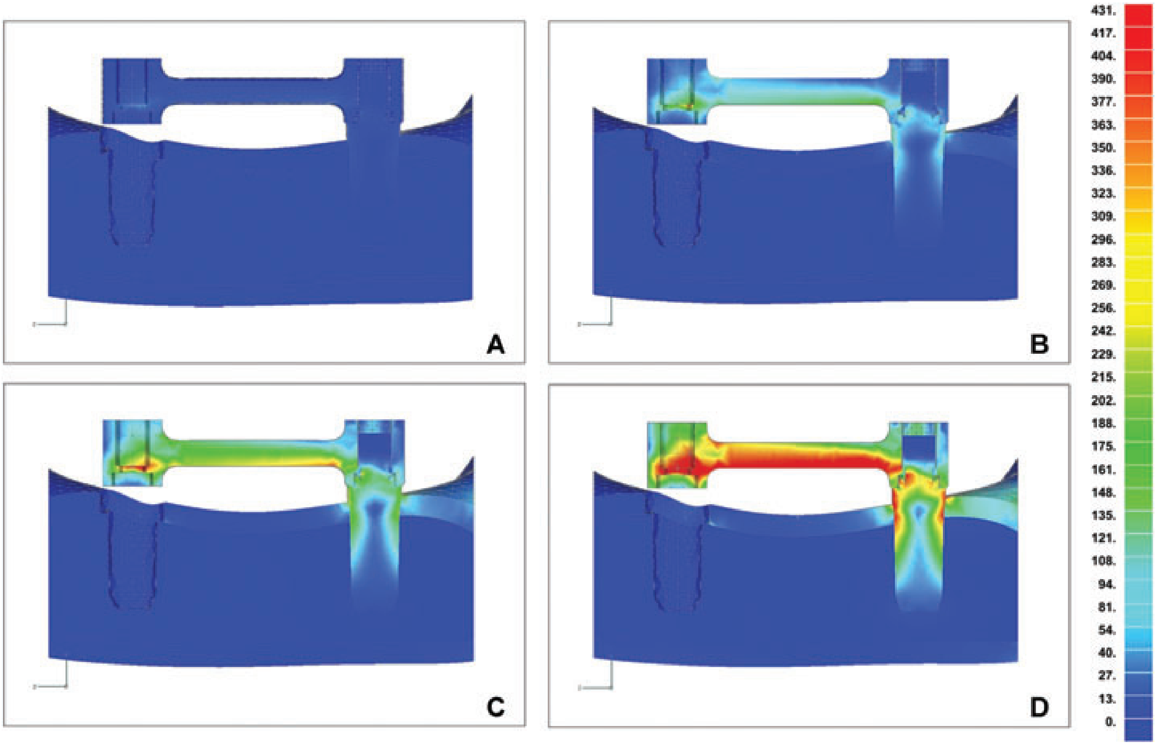

Figure 2 Von Mises stress (MPa) distribution in the models with different horizontal misfits for the gold bar framework: (A) 10 μm; (B) 50 μm; (C) 100 μm; and (D) 200 μm.

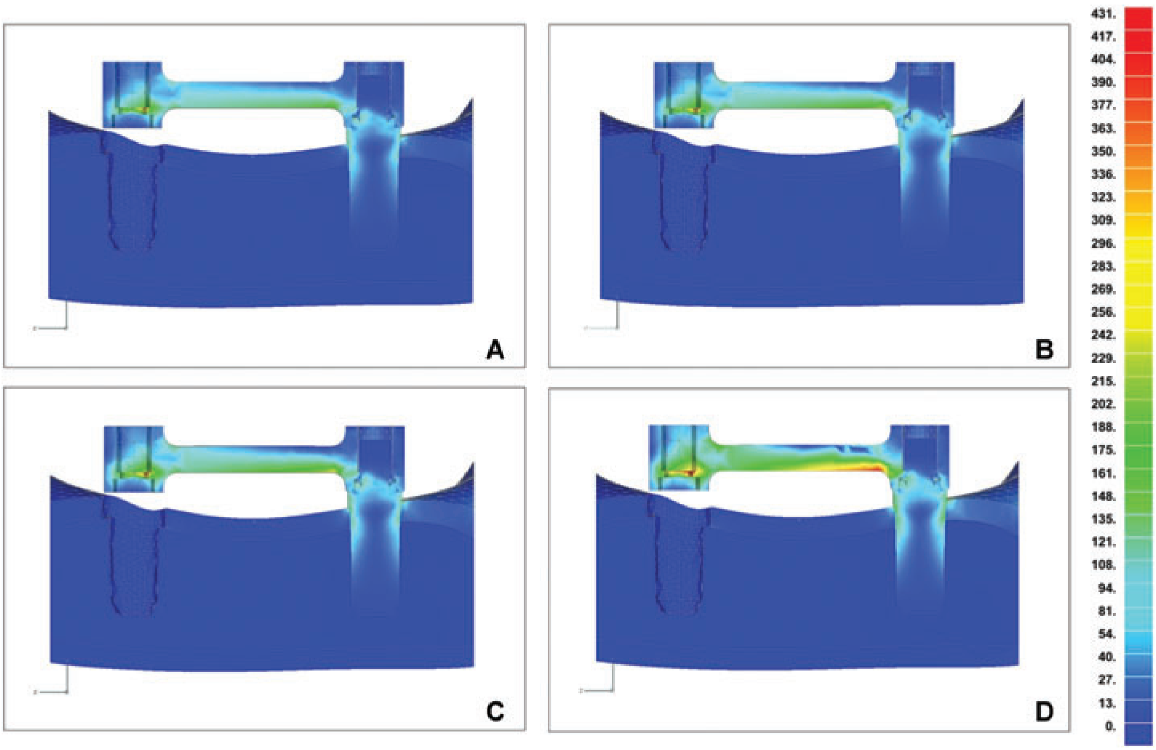

Figure 3 Von Mises stress (MPa) distribution in the models with different bar framework materials for 50 μm of misfit: (A) gold alloy; (B) silver–palladium alloy; (C) commercially pure titanium; and (D) cobalt–chromium alloy.

Table 2 Maximum stress (MPa) in the models testing horizontal misfit

	Structures of the model			
Model	Cortical bone	Bar	Retaining screw	Implant
Au/10	33	38	31	25
Au/50	165	195	155	127
Au/100	330	395	312	253
Au/200	660	810	629	330

Results

Von Mises stresses that occurred in the bar framework, periimplant bone tissue, retaining screw, and implant for all models are presented in Figures 2 and 3. The maximum stress values found in these structures are presented in Tables 2 and 3. The cancellous bone presented inconsiderable changes in stress values under the various tested conditions.

Horizontal misfit effect

Figure 2 represents distribution of von Mises stresses within the overdenture-retaining bar system concerning the different levels of horizontal misfits using gold alloy as the bar material. Stresses were concentrated in the inferior region of the bar, in the whole diameter of the retaining-screw neck, along the cervical and middle third of the implant, and in the cortical bone tissue surrounding the implant. The misfit amplification presented a great increase in stress values in these structures (Table 2).

Bar material effect

Figure 3 represents the distribution of von Mises stresses within the overdenture-retaining bar system for the different bar materials with 50 μm horizontal misfit between bar and implant. Stresses were concentrated in the same areas as the horizontal misfit effect; however, the higher stiffness of the bar presented a considerable increase in the stress levels in the cortical bone tissue and bar framework, while the retaining screw and implant presented few changes in the stress values (Table 3).

Discussion

FEA is an established theoretical technique used in engineering problems. The role of bioengineering cannot be underestimated, and biomechanical principles have been verified in many studies.[25] The basic purpose of these studies is to extrapolate the findings relevant to the risk factors instead of experiencing them empirically in clinical applications.

The model used in this study implied several assumptions regarding the simulated structures. The structures in the model were all assumed to be homogeneous, isotropic, and linearly elastic. The proprieties of the materials modeled in this study, particularly the living tissues, however, are different. Due to the lack of precise information regarding the material properties of bone, cortical and cancellous bone were assumed to have these properties.[24] The other assumptions were implemented in the model after several procedures obtaining the model stability, which was regarded as relevant to engineering and clinical aspects.

The FEA showed great changes on the stress levels created in the overdenture-retaining bar system with respect to the different horizontal misfits. Although the horizontal misfits were tested only with Au alloy, it can be suggested that the other alloys demonstrate the same pattern of presenting greater values of stress according to the rise in horizontal misfit, but with higher values due to being stiffer than Au alloys. The misfit amplification induced a considerable increase in the concentration of static stresses in the bar, in the whole diameter of the retaining-screw neck, along the cervical and middle third of the implant, and in the cortical bone tissue surrounding the implant. These data are in agreement with the first hypothesis. A previous study[17] found that amplification of vertical misfit seems to have an influence on the stress distribution in the bar framework, while in periimplant bone tissue, the increase in stress levels was not considerable. These findings suggest that horizontal misfits may be more prejudicial to multi-unit prostheses than vertical misfits are.

Many studies have considered only the vertical misfit as the distortion of the piece.[4,13,15,17] The findings of the current study seem to suggest that horizontal misfits always should be evaluated in laboratory or clinical studies comparing framework fabrication techniques. Methodologies using digital or optical 3D readings can make the results of the research studies more reliable.[26]

Concerning the different bar materials, the Au alloys showed lower stress levels, principally in the bar framework. For other compounds of the system, such as the cortical bone and the retaining screw and implant, stress values were not considerably lower. The bar structure appeared to be more sensitive to the material stiffness, in agreement with recent literature.[17] However, these findings disagree with Natali et al's findings,[27] which suggested that lower framework resiliency could reduce stress levels transferred to the periimplant bone tissue.

The different materials were analyzed only with a horizontal misfit of 50 μm; higher horizontal misfits using materials with higher stiffness properties could induce more static stresses to the system. This misfit was chosen due to previous studies, such as the one conducted by Al-Fadda et al,[26] who verified the tridimensional accuracy of various methods for fabricating implant-prosthodontics frameworks with five implants and found an average of 49.2 μm of horizontal misfit (ranging from 21.4 to 134.8 μm) in conventional casting procedures. A previous study[28] evaluated the accuracy of three-unit implant

Table 3 Maximum stress (MPa) in the models testing bar material

	Structures of the model			
Model	Cortical bone	Bar	Retaining screw	Implant
Au/50	165	195	155	127
Ag–Pd/50	178	225	159	135
Ti/50	181	229	159	137
Co–Cr/50	188	253	161	141

frameworks and found an average of 48-μm horizontal misfit after casting. Many procedures, including soldering[28] and the use of a laser-scanned computer milled framework (Nobel Biocare),[26] among others, can reduce framework misfit. Thus, it seems prudent to optimize fit using a combination of the best available clinical and laboratory materials and methods when fabricating implant frameworks.[26] Clinically, the lowest horizontal misfit must be pursued, principally to decrease stress concentrations, since with the reduction of the horizontal misfit, the stress levels in the cortical periimplant bone tissue, bar framework, retaining screw, and implant of the overdenture-retaining bar system will be reduced, too.

In addition to acknowledging and supplementing studies using FEA to evaluate stress in bone tissue, it is essential to conduct more studies to show quantitative stress with respect to positive remodeling to the osseointegration. Other factors already under investigation, such as loading geared by a clip and configuration of the bar framework, may influence stress distribution in the bar-clip system. Another important factor needing attention is that laboratory studies comparing or evaluating techniques of framework fabrication should always consider the 3D misfit, evaluating vertical and, principally, horizontal misfits; however, the levels that actually cause biological response, such as resorption and remodeling of the bone, are not comprehensively known. Therefore, the stress data provided for FEA requires substantiation by clinical research.[29]

Conclusions

Within the limitations of this FEA, it was possible to conclude that:

1. The amplification of horizontal misfit increased the levels of static stress in the structures of the overdenture-retaining bar system.
2. The stiffness of the bar framework presented a lower effect in the static stress levels.

Acknowledgements

The authors thank the Department of Product Development, Center of Information Technology Renato Archer, Campinas, SP, in the persons of Pedro Yoshito Noritomi and André Uehara, for its generous help with the FEA. We also thank Prof. Dr. Ricardo Teixeira Abreu for his help in the creation of the geometric and FE model.

References

1. Kimoto S, Pan S, Drolet N, et al: Rotational movements of mandibular two-implant overdentures. Clin Oral Implants Res 2009;20:838-843
2. Romero GG, Engelmeier R, Powers JM, et al: Accuracy of three corrective techniques for implant bar fabrication. J Prosthet Dent 2000;84:602-607
3. Zarb GA, Symington JM: Osseointegrated dental implants: preliminary report on a replication study. J Prosthet Dent 1983;50:271-276
4. al-Turki LE, Chai J, Lautenschlager EP, et al: Changes in prosthetic screw stability because of misfit of implant-supported prostheses. Int J Prosthodont 2002;15:38-42
5. Richter EJ: Basic biomechanics of dental implants in prosthetic dentistry. J Prosthet Dent 1989;61:602-609
6. Hussaini S, Wong T: One clinical visit for a multiple implant restoration master cast fabrication. J Prosthet Dent 1997;78:550-553
7. Assif D, Marshak B, Schmidt A: Accuracy of implant impression techniques. Int J Oral Maxillofac Implants 1996;11:216-222
8. Rubenstein JE, Ma T: Comparison of interface relationships between implant components for laser-welded titanium frameworks and standard cast frameworks. Int J Oral Maxillofac Implants 1999;14:491-495
9. Carr AB, Stewart RB: Full-arch implant framework casting accuracy: preliminary in vitro observation for in vivo testing. J Prosthodont 1993;2:2-8
10. Goodacre CJ, Kan JY, Rungcharassaeng K: Clinical complications of osseointegrated implants. J Prosthet Dent 1999;81:537-552
11. Taylor TD: Prosthodontic problems and limitations associated with osseointegration. J Prosthet Dent 1998;79:74-78
12. Gratton DG, Aquilino SA, Stanford CM: Micromotion and dynamic fatigue properties of the dental implant-abutment interface. J Prosthet Dent 2001;85:47-52
13. Kunavisarut C, Lang LA, Stoner BR, et al: Finite element analysis on dental implant-supported prostheses without passive fit. J Prosthodont 2002;11:30-40
14. Michaels GC, Carr AB, Larsen PE: Effect of prosthetic superstructure accuracy on the osteointegrated implant bone interface. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;83:198-205
15. Carr AB, Gerard DA, Larsen PE: The response of bone in primates around unloaded dental implants supporting prostheses with different levels of fit. J Prosthet Dent 1996;76:500-509
16. Bergendal B, Palmqvist S: Laser-welded titanium frameworks for fixed prostheses supported by osseointegrated implants: a 2-year multicenter study report. Int J Oral Maxillofac Implants 1995;10:199-206
17. Abreu RT, Spazzin AO, Noritomi PY, et al: Influence of material of overdenture-retaining bar with vertical misfit on three-dimensional stress distribution. J Prosthodont 2010;19:425-431
18. Parel SM: Modified casting technique for osseointegrated fixed prosthesis fabrication: a preliminary report. Int J Oral Maxillofac Implants 1989;4:33-40
19. Abu-Hammad OA, Harrison A, Williams D: The effect of a hydroxyapatite-reinforced polyethylene stress distributor in a dental implant on compressive stress levels in surrounding bone. Int J Oral Maxillofac Implants 2000;15:559-564
20. Sakaguchi RL, Borgersen SE: Nonlinear finite element contact analysis of dental implant components. Int J Oral Maxillofac Implants 1993;8:655-661
21. Korioth TW, Johann AR: Influence of mandibular superstructure shape on implant stresses during simulated posterior biting. J Prosthet Dent 1999;82:67-72
22. Craig RG: Restorative Dental Materials (ed 8). St. Louis. Mosby, 1989
23. Lewinstein I, Banks-Sills L, Eliasi R: Finite element analysis of a new system (IL) for supporting an implant-retained cantilever prosthesis. Int J Oral Maxillofac Implants 1995;10:355-366

24. Humphries RM, Yaman P, Bloem TJ: The accuracy of implant master casts constructed from transfer impressions. Int J Oral Maxillofac Implants 1990;5:331-336
25. Hannam AG: Current computational modelling trends in craniomandibular biomechanics and their clinical implications. J Oral Rehabil 2011;38:217-234
26. Al-Fadda SA, Zarb GA, Finer Y: A comparison of the accuracy of fit of 2 methods for fabricating implant-prosthodontic frameworks. Int J Prosthodont 2007;20:125-131
27. Natali AN, Pavan PG, Ruggero AL: Evaluation of stress induced in peri-implant bone tissue by misfit in multi-implant prosthesis. Dent Mater 2006;22:388-395
28. Zervas PJ, Papazoglou E, Beck FM, et al: Distortion of three-unit implant frameworks during casting, soldering, and simulated porcelain firings. J Prosthodont 1999;8: 171-179
29. Ding X, Zhu XH, Liao SH, et al: Implant-bone interface stress distribution in immediately loaded implants of different diameters: a three-dimensional finite element analysis. J Prosthodont 2009;18:393-402