Influence of Platform and Abutment Angulation on Peri-Implant Bone. A Three-Dimensional Finite Element Stress Analysis

Ana Paula Martini, DDS[1]*
Rosália Moreira Barros, DDS, MD[2]
Amilcar Chagas Freitas Júnior, DDS[1]
Eduardo Passos Rocha, DDS, PhD[1]
Erika Oliveira de Almeida, DDS, PhD[1]
Cacilda Cunha Ferraz, DDS, MD[2]
Maria Cristina Jimenez Pellegrin, DDS, PhD[2]
Rodolfo Bruniera Anchieta, DDS, PhD[1]

The aim of this study was to evaluate stress distribution on the peri-implant bone, simulating the influence of Nobel Select implants with straight or angulated abutments on regular and switching platform in the anterior maxilla, by means of 3-dimensional finite element analysis. Four mathematical models of a central incisor supported by external hexagon implant (13 mm × 5 mm) were created varying the platform (R, regular or S, switching) and the abutments (S, straight or A, angulated 15°). The models were created by using Mimics 13 and Solid Works 2010 software programs. The numerical analysis was performed using ANSYS Workbench 10.0. Oblique forces (100 N) were applied to the palatine surface of the central incisor. The bone/implant interface was considered perfectly integrated. Maximum (σ_{max}) and minimum (σ_{min}) principal stress values were obtained. For the cortical bone the highest stress values (σ_{max}) were observed in the RA (regular platform and angulated abutment, 51 MPa), followed by SA (platform switching and angulated abutment, 44.8 MPa), RS (regular platform and straight abutment, 38.6 MPa) and SS (platform switching and straight abutment, 36.5 MPa). For the trabecular bone, the highest stress values (σ_{max}) were observed in the RA (6.55 MPa), followed by RS (5.88 MPa), SA (5.60 MPa), and SS (4.82 MPa). The regular platform generated higher stress in the cervical periimplant region on the cortical and trabecular bone than the platform switching, irrespective of the abutment used (straight or angulated).

Key Words: oral implantology, finite element analysis, stress, bone

INTRODUCTION

The finite element analysis (FEA) method is accepted as an important tool for understanding mechanical responses in biologic research and in the study of stresses resulting from masticatory forces applied on supporting bone structures,[1] especially when implant dentistry is considered, in which the biomechanical aspects of the denture have a significant influence on the success of osseointegrated implants. FEA enables the biomechanical analysis of stresses induced by the entire system under different clinical situations. One of the aspects of implant therapy that represents a great challenge is the placement of implants and subsequent restoration in esthetic areas because in these regions the peri-implant bone level and consequent positioning of the gingival tissue are

[1] Araçatuba School of Dentistry, UNESP – Universidade Estadual Paulista, Araçatuba, SP, Brazil.
[2] Post Graduate Center, São Leopoldo Mandic School Campinas, São Paulo, Brazil.
* *Corresponding author,* e-mail: martini.anapaula@gmail.com
DOI: 10.1563/AAID-JOI-D-11-00029

critical factors of the esthetic result. Preservation of the bone crest around the implant and maintenance of the gingival papilla are of fundamental importance.[2,3] The platform switching concept, introduced by Gardner[4] and Lazzara and Porter,[5] affirms that the use of abutments with a smaller diameter in an implant with a larger diameter allows a potential increase in the preservation of the bone crest, favoring the maintenance of the supporting tissues, which is very important in the outcome of treatment.[6] Thus, the aim of the present study was to make a linear evaluation by 3-dimensional FEA of the distribution of stresses generated by implants in the maxilla, in the region of the left central incisor, using two different types of abutments—straing and angulated, in regular and in platforms switching.

Materials and Methods

After obtaining approval from the Human Research Ethics Committee (Process 2008/01845) and a signed term of free and informed consent from the patient, a computerized tomography (CT) scan of the patient's maxilla was performed to obtain the CT images in DICOM format.

Based on a tomography image, several slices were obtained after scanning the anterior maxillary bone. For the solid model design, the slices were serially selected using Mimics, version 13 (Materialise, Leuven, Belgium) for 3-dimensional reconstruction. All maxillary structures (cortical bone and trabecular bone) were included in the solid model.

After this, the solid model was exported from SolidWorks 2010 software (Inovart, São Paulo, SP, Brazil). The dental implant, implant abutments, screw, and adaptor were modeled in SolidWorks software, using digitalized photographs and x-rays of dental implants and implant abutments.[7] All structures were created with real dimensions and features. The incisor crown was created based on previous microtomography image of natural teeth.

Following, based on Boolean's operations (implant, abutment, screw, adaptor, crown, and bone) were grouped to form study models. Thus were the four models used in this study created, varying the implant (regular or switching) and the abutment (straight or angulated) (Figure 1). The models contained the implant, abutment, adaptor, and fixation screw placed in the anterior segment of the maxilla with cortical and trabecular bone corresponding to the region of the left central incisor. Nobel Biocare, Replace Select Tapered (Nobel Biocare, Zürich, Switzerland) cylindrical implants with the thread design, 13 mm $\times$ 5 mm, made of commercially pure titanium, were connected to the 5-mm abutments for a conventional platform and 4.1 mm for platform switching, straight and angulated at 15°. In the Nobel System, an adaptor (Adapter PS WP-RP) is used to transform the conventional connection (implants and abutments of the same diameter) into platform switching.

The implants were restored with metal ceramic crowns, the superstructure being made of gold and its respective lining of feldspathic porcelain, measuring 7 mm in the vestibulolingual direction, 9 mm in the mesiodistal direction, and 10 mm high. Considering that the simulated prosthesis was cemented, 50 μm of space was kept between the crown and abutment, referring to the cementation line of parts. The mechanical properties of Panavia self-etch resin cement (Kuraray, Osaka, Japan) were used. The models were denominated according to their variations: RS and RA (regular platform with straight and angulated abutment, respectively) and SS and SA (platform switching with straight and angulated abutment, respectively).

After producing the models, they were transported to the finite element program ANSYS Workbench 10.0 software (Swanson Analysis Inc, Houston, Pa) to determine the regions and generate the finite element mesh (Figure 2).

The mechanical properties of the materials were based on the specific literature (Table 1).[8–10] All materials were considered isotropic, homogeneous, and linearly elastic.

The 4 models had the same loading force applied on the lingual surface of the prosthetic crown, in incisal region, with a magnitude of 100 N[11] in 45° with the long axis of the implant (Figure 3). The fixed support was determined along the 3 Cartesian axes ($x = y = z = 0$) to characterize the boundary condition. The bone-implant interface was considered perfectly integrated.[12,13]

Parabolic tetrahedral elements were used for mesh refinement, which was established by the convergence of analysis (6%).[14] The models showed a number of elements ranging from 106 237 to

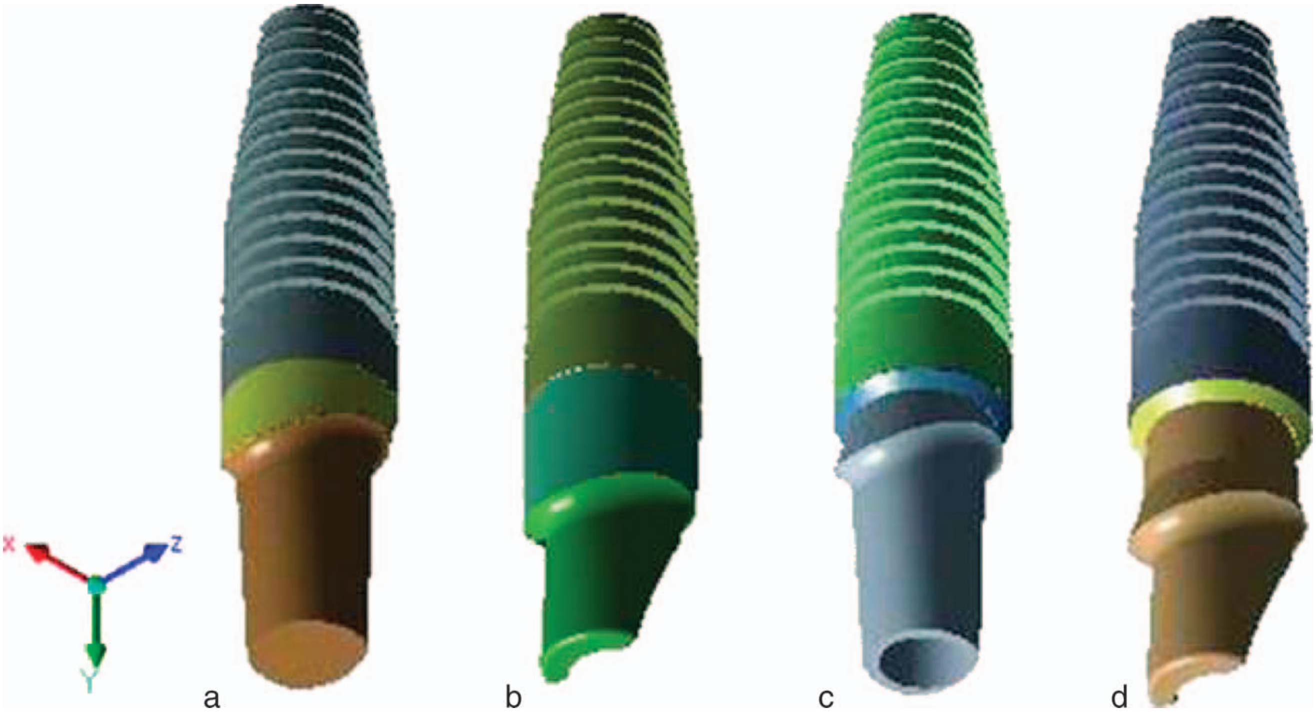


Figure 1. Models illustrating implants connected to straight and angulated abutments on a regular and a switching platform. (a) Regular platform and straight abutment. (b) Regular platform and angulated abutment. (c) Platform switching and straight abutment. (d) Platform switching and angulated abutment.

115 079 and a number of nodes ranging from 170 880 to 184 749.

For analysis of the results, the maximum (σ_{max}) and minimum (σ_{min}) principal stress values were obtained for the cortical and trabecular bones. According to Rocha et al,[15] these analysis criteria are appropriate for predicting failures in nonductile materials.

Results

All of the values obtained in the analyses of the models are shown in Table 2. Other analysis criteria were added to complement the information obtained. In all cases, it may be observed that the highest σ_{max} values were concentrated in the cervical palatine region of the cortical bone (Figure 4).

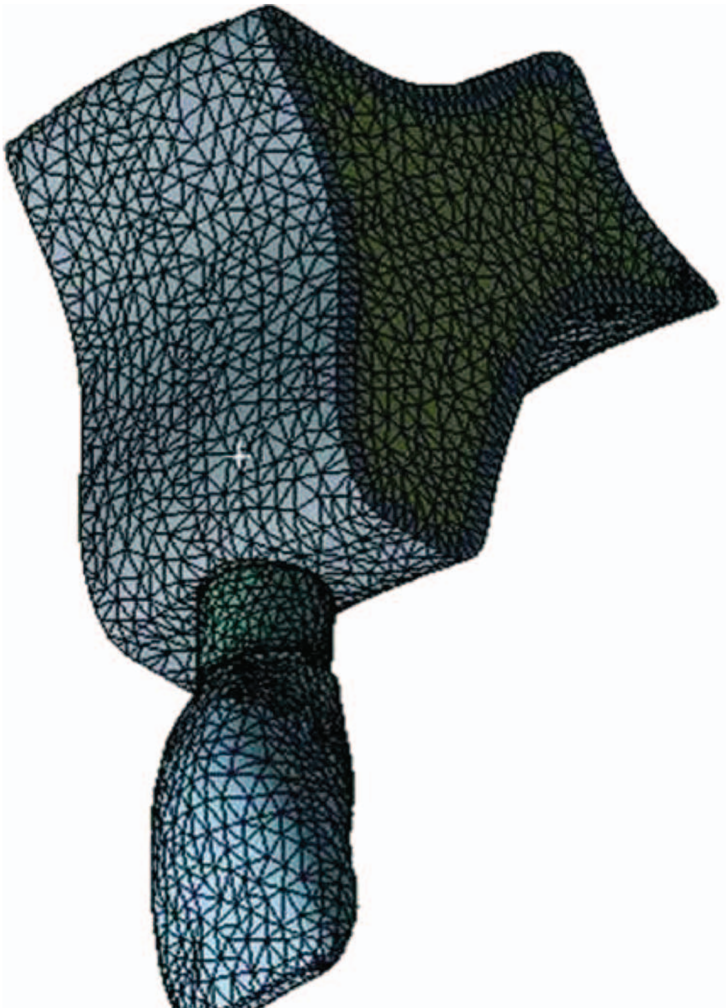
The models with platform switching (SS and SA) generated lower levels of σ_{max} than the implants with conventional platform (RS and RA). For the cortical bone, in the models with straight abutments, there was a 5.5% reduction in σ_{max} when platform switching and conventional platforms were compared. In the angulated abutments, there was a 12% reduction in the models with platform switching.

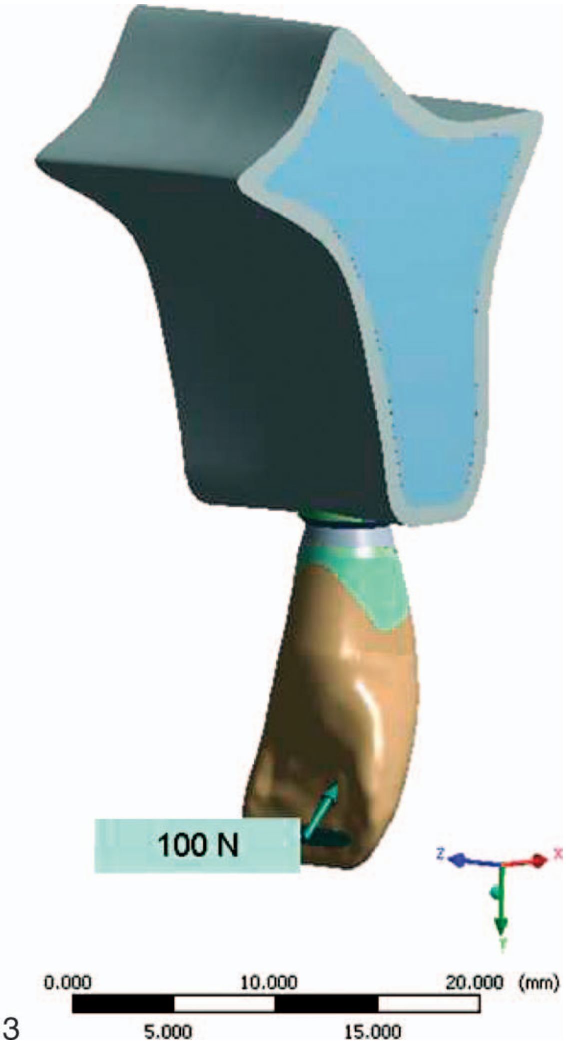
However, the greatest variations were observed when the abutments used were analyzed. Angulated abutments (RA and SA) generated higher σ_{max} values in the cortical bone in comparison with the straight abutments (RS and SS). When the conventional platform was analyzed, there was a 25% increase in σ_{max}, whereas in the models with platform switching the angulated abutments caused an 18.5% increase. Similar behavior could be observed in the trabecular bone.

Table 1

Mechanical properties of the materials used for the finite element analysis model

Material	Young's Modulus (MPa)	Poisson's Ratio	References
Cortical bone	14 000	0.30	Kong et al
Trabecular bone	1370	0.30	Kong et al
Titanium	110 000	0.35	Kong et al
Ceramic	68 900	0.28	Kong et al
Gold (superstructure)	90 000	0.30	Lin et al
Cement	18 600	0.28	Lanza et al


2



3

FIGURES 2 AND 3. FIGURE 2. Completed model with finite element mesh. **FIGURE 3.** Model representing the application of the force in oblique direction on the lingual face of prosthetic crown.

DISCUSSION

There have been various studies in the literature on stress analysis in the implant/denture system with the use of finite element analysis.[16–19] With the use of simulations, it is possible to observe the biomechanical behavior of this system, which cannot be measured experimentally, in order to add to and guide the search for information

TABLE 2

Maximum (σ_{max}) and minimum (σ_{min}) principal stress values, equivalent stress (σ_{vM}), and maximum (ε_{max}) and minimum (ε_{min}) principal elastic strain on the cortical and trabecular bone for the models RS (regular platform and straight abutment), RA (regular platform and angulated abutment), SS (platform switching and straight abutment), and SA (platform switching and angulated abutment)

	σ_{max} Cortical Bone	σ_{min} Cortical Bone	σ_{vM} Cortical Bone	ε_{max} Cortical Bone	ε_{min} Cortical Bone	σ_{max} Trabecular Bone	σ_{min} Trabecular Bone	σ_{vM} Trabecular Bone	ε_{max} Trabecular Bone	ε_{min} Trabecular Bone
RA	51	−45.7	38.7	2.92e−003	−2.91e−003	6.55	−1.56	5.53	3.9e−003	−3.74e−003
RS	38.6	−38.8	30.8	2.29e−003	−2.42e−003	5.88	−2.87	6.85	3.34e−003	−2.82e−003
SA	44.8	−38.9	37	2.67e−003	−2.77e−003	5.6	−5.16	5.84	3.94e−003	−3.75e−003
SS	36.5	−32.3	30	2.08e−003	−2.28e−003	4.82	−3.82	6.66	3.32e−003	−2.79e−003

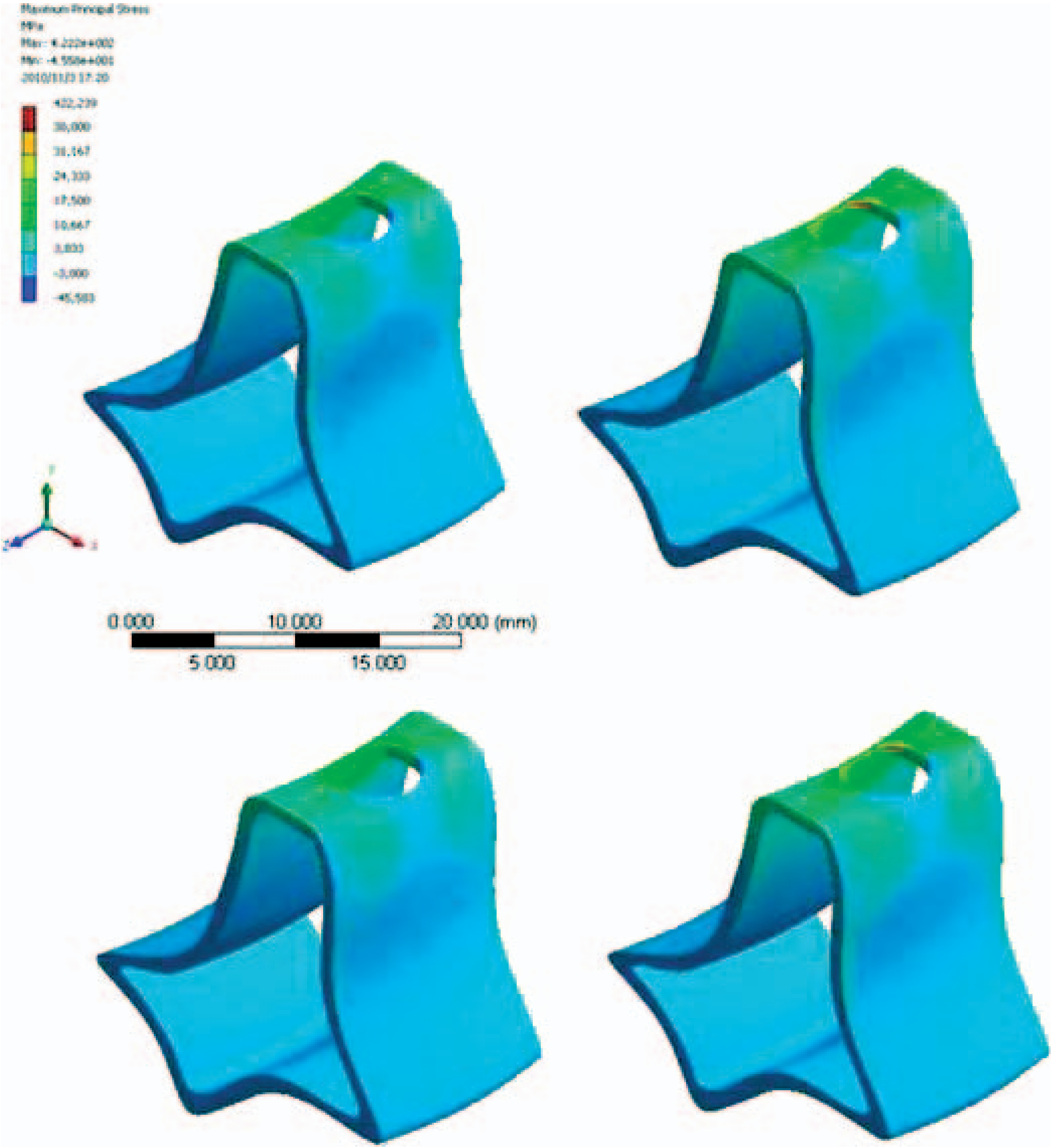


Figure 4. Maximum principal stress on cortical bone in models RS (regular platform and straight abutment), RA (regular platform and angulated abutment), SS (platform switching and straight abutment), and SA (platform switching and angulated abutment).

obtained in in vivo and in vitro studies. The development of numerical models makes it possible to evaluate the mechanical behavior of the bone/implant/denture system and estimate fundamental variables, such as stress and deformation of the bone tissue and their possible consequences and damage caused.[20]

Various existent theories have tried to explain the changes observed in the bone crest height after the insertion of implant-supported prostheses, considering and suggesting alternatives that may minimize these negatives changes, from the use of a shock-absorbing material such as acrylic resin in the form of acrylic resin artificial teeth culminating in the use of the platform switching.[1,4,5] Previous studies demonstrated that the use of platform switching, promoting the displacement of the external edge of the abutment-implant interface horizontally towards the center, distancing it from the bone crest, would limit bone resorption around the coronal portion of the implant.[21–24] The space between the abutment-implant, a microgap, could be a reservoir of bacteria, which may cause inflammation of the peri-implant soft tissue and could cause bone resorption.[2,4]

When analyzing the results obtained in the present study, it could be observed that these were in agreement with the results found in the literature, as it was possible to observe that in the models with platform switching, SS and SA, the stress values on the peri-implant tissue were lower in comparison with those of the conventional platform, RS and RA. Similar results were found by Maeda et al,[25] who evaluated the biomechanical advantages of platform switching using abutments with different diameters in implants and found lower stress values when platform switching was used. It was observed that a lower concentration of stresses was transmitted to the peri-implant bone tissue, which could diminish the occurrence of microdamage and result in less bone resorption around the implant platform,[21] a factor which produces a superior esthetic result and greater predictability of maintaining the gingival papilla. De Sanctis et al[26] investigated the changes in soft tissue adjacent to different types of implants, including the platform switching, installed in dogs. The animals were killed 6 weeks after surgery and the effect cannot be observed, increase or reduction, in the dimensions of the soft tissues by histometric analysis, constituting a limitation of this study. However, the authors observed a tendency towards longer dimensions of the epithelium with all of the implant systems tested, and the different length of the junctional epithelium and a different dimension of the overall supracrestal soft tissue barrier may be of clinical relevance and deserves further investigation.

In spite of the more favorable results found with straight abutments, the need for correcting the position of inclined implants with the use of angulated abutments cannot be overlooked. This is the case particularly in the anterior region, where the esthetic factor is determinant, and in other sites where the anatomic structures make it impossible to position the implant adequately.[27,28] Moreover, oblique loading more faithfully reproduces the clinical situations that dentures are submitted to during function, creating a greater mechanical demand on the entire set, thus constituting an important factor with regard to the results obtained.[29]

Although there are findings in this study that complement the literature with regard to the influence of platform switching on peri-implant bone when straight and angulated abutments are used, simplifications were used in the analysis, such as a lack of evidence of contact between bone and implant and the representation of bone with isotropic and homogeneous properties.[30] Further studies should be designed to add more data to the existent research, with a view to more faithful representation in the models as far as the conditions existent in vivo are concerned.

Conclusions

Based on the analysis used in the present study, it was possible conclude that:

- The preponderant location of maximum principal stress was on the cortical bone, in the cervical region of the palatine face.
- The implants with regular platforms produced greater stress in the cervical region of the cortical and medullar bone than the implants with platform switching, irrespective of the abutment angulation.
- The angulated abutments produced greater stress on the peri-implant bone than the straight abutments.
- The combination of platform switching/straight abutment presented the best biologic behavior in stress distribution on the adjacent bone tissue.

Abbreviations

CT: computerized tomography
FEA: finite element analysis

RA: regular platform with angulated abutment
RS: regular platform with straight abutment
SA: platform switching with angulated abutment
SS: platform switching with straight abutment

References

1. Skalak R. Biomechanical considerations in osseointegrated prostheses. *J Prosthet Dent*. 1983;49:843–848.

2. Canullo L, Iurlaro G, Iannello G. Double-blind randomized controlled trial study on post-extraction immediately restored implants using the switching platform concept: soft tissue response. *Clin Oral Implants Res*. 2009;20:414–420.

3. Chang M, Wennstrom JL. Longitudinal changes in tooth/single-implant relationship and bone topography: an 8-year retrospective analysis. *Clin Implant Dent Relat Res*. 2010. 2012;14:388–394.

4. Gardner DM. Platform switching as a means to achieving implant esthetics. *N Y State Dent J*. 2005;71:34–37.

5. Lazzara RJ, Porter SS. Platform switching: a new concept in implant dentistry for controlling post-restorative crestal bone levels. *Int J Periodontics Restorative Dent*. 2006;26:9–17.

6. Gehrke P, Lobert M, Dhom G. Reproducibility of the pink esthetic score rating soft tissue esthetics around single-implant restorations with regard to dental observer specialization. *J Esthet Restor Dent*. 2008;20:375–385.

7. Freitas AC Jr, Rocha EP, dos Santos PH, de Almeida EO, Anchieta RB. All-ceramic crowns over single implant zircon abutment. Influence of Young's modulus on mechanics. *Implant Dent*. 2010;19:539–548.

8. Kong L, Hu K, Li D, et al. Evaluation of the cylinder implant thread height and width: a 3-dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 2008;23:65–74.

9. Lin CL, Wang JC, Chang WJ. Biomechanical interactions in tooth implant-supported fixed partial dentures with variations in the number of splinted teeth and connector type: a finite element analysis. *Clin Oral Implants Res*. 2008;19:107–117.

10. Lanza A, Aversa R, Rengo S, Apicella D, Apicella A. 3D FEA of cemented steel, glass and carbon posts in a maxillary incisor. *Dent Mater*. 2005;21:709–715.

11. Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three-dimensional finite element analysis. *J Prosthet Dent*. 2008;100:422–431.

12. Asmussen E, Peutzfeldt A, Sahafi A. Finite element analysis of stresses in endodontically treated, dowel-restored teeth. *J Prosthet Dent*. 2005;94:321–329.

13. Sorrentino R, Aversa R, Ferro V, et al. Three-dimensional finite element analysis of strain and stress distributions in endodontically treated maxillary central incisors restored with different post, core and crown materials. *Dent Mater*. 2007;23:983–993.

14. Almeida EO, Rocha EP, Freitas AC Jr, Martin MM Jr. Finite element stress analysis of edentulous mandibles with different bone types supporting multiple-implant superstructures. *Int J Oral Maxillofac Implants*. 2010;25:1108–1114.

15. Rocha EP, Anchieta RB, Freitas AC Jr, Almeida EO, Cattaneo PM, Ko CC. Mechanical behavior of ceramic veneer in zirconia-based restorations: a 3-dimensional finite element analysis using microcomputed tomography data. *J Prosthet Dent*. 2011;105:14–20.

16. Pessoa RS, Vaz LG, Marcantonio E Jr, Sloten JV, Duyck J, Jaecques SV. Biomechanical evaluation of platform switching in different implant protocols: computed tomography-based three-dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 2010;25:911–919.

17. Shen WL, Chen CS, Hsu ML. Influence of implant collar design on stress and strain distribution in the crestal compact bone: a three-dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 2010;25:901–910.

18. Lan TH, Pan CY, Lee HE, Huang HL, Wang CH. Bone stress analysis of various angulations of mesiodistal implants with splinted crowns in the posterior mandible: a three-dimensional finite element study. *Int J Oral Maxillofac Implants*. 2010;25:763–770.

19. Anitua E, Tapia R, Luzuriaga F, Orive G. Influence of implant length, diameter, and geometry on stress distribution: a finite element analysis. *Int J Periodontics Restorative Dent*. 2010;30:89–95.

20. Natali NA, Pavan PG, Ruggero AL. Analysis of bone-implant interaction phenomena by using a numerical approach. *Clin Oral Implants Res*. 2006;17:67–74.

21. Sahin S, Cehreli MC, Yaçin E. The influence of functional forces on the biomechanics of implant-supported prostheses—a review. *J Dent*. 2002;30:271–282.

22. Tabata LF, Assunção WG, Barão VAR, de Sousa EA, Gomes EA, Delben JA. Implant platform switching: biomechanical approach using two-dimensional finite element analysis. *J Craniofac Surg*. 2010;21:182–187.

23. Canullo L, Rasperini G. Preservation of peri-implant soft and hard tissues using platform switching of implants placed in immediate extraction sockets: a proof-of-concept study with 12- to 36-month follow-up. *Int J Oral Maxillofac Implants*. 2007;22:995–1000.

24. Cappiello M, Luongo R, Di Iorio D, Bugea C, Cocchetto R, Celletti R. Evaluation of peri-implant bone loss around platform-switched implants. *Int J Periodontics Restorative Dent*. 2008;28:347–355.

25. Maeda Y, Miura J, Taki I, Sogo M. Biomechanical analysis on platform switching: is there any biomechanical rationale? *Clin Oral Implants Res*. 2007;18:581–584.

26. De Santis M, Vignoletti F, Discepoli N, Muñoz F, Sanz M. Immediate implants at fresh extraction sockets: an experimental study in the beagle dog comparing four different implant systems. Soft tissue findings. *J Clin Periodontol*. 2010;37:769–776.

27. Lim TJ, Csillag A, Irinakis T, Nokiani A, Wiebe CB. Intentional angulation of an implant to avoid a pneumatized maxillary sinus: a case report. *J Can Dent Assoc*. 2004;70:164–168.

28. Saab XE, Griggs JA, Powers JM, Engelmeier RL. Effect of abutment angulation on the strain on the bone around an implant in the anterior maxilla: a finite element study. *J Prosthet Dent*. 2007;97:85–92.

29. Danza M, Quaranta A, Carinci F, Paracchini L, Pompa G, Vozza I. Biomechanical evaluation of dental implants in D1 and D4 bone by finite element analysis [in English, Italian]. *Minerva Stomatol*. 2010;59:305–313.

30. Cochran DL. The scientific basis for and clinical experiences with Straumann implants including the ITI dental implants system: a consensus report. *Clin Oral Implants Res*. 2000;11:33–58.