Comparative finite element analysis of stress distribution in pilars of fixed dentures supported with tilted versus nontilted posterior implants

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Abstract

Introduction: According to the all-on-four treatment concept, tilted posterior implants reduce distal cantilever length. **Objective:** By means of three-dimensional finite element analysis, to elucidate the biomechanics of these devices and evaluate the use of tilted versus nontilted posterior implants and angled abutments in the treatment of the edentulous jaws. **Methods:** Four three-dimensional mandible models were created to simulate cortical and cancellous bone. The models received four parallel implants with straight abutments, or two vertical implants and two posterior implants titled at 17 or 30 degrees with straight or angled abutments. All models received axial loading or off-axis loading on one or both sides of the prosthesis. **Results:** The greatest stress concentrations were found for vertical implants and angled abutments. Tilted posterior implants favored stress distribution. **Conclusion:** The all-on-four treatment concept and the use of straight abutments favored the biomechanics of implant-supported full dentures.

Keywords: Vertical implants. Tilted implants. Finite element analysis.

How to cite this article: Carvalho LP, Maior BS, Feltrin PP, Zanetti AL, Zanetti RV, Carvalho AM. Comparative finite element analysis of stress distribution in pilars of fixed dentures supported with tilted versus nontilted posterior implants. Dental Press Implantol. 2013 Jan-Mar;7(1):95-104.

» The authors inform they have no associative, commercial, intellectual property or financial interests representing a conflict of interest in products and companies described in this article.

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Submitted: December 04, 2012
Revised and accepted: February 28, 2013

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Introduction

The rehabilitation of atrophic mandibles is a challenge for oral rehabilitation specialists. Patients with edentulous mandibles have poorer mastication and undergo facial changes, a reduction of the lower third of the face, chin projection, deterioration of self-esteem, and limitations to their social life. Rehabilitation of this clinical condition usually consists of conventional removable complete dentures, implant-retained prosthesis and overdentures, or implant-supported fixed complete dentures, which ensures efficient mastication and has the highest level of patient acceptance.[23]

However, implants cannot be placed in the posterior region of atrophic edentulous jaws because of insufficient bone height and the presence of important anatomic landmarks, such as the mandibular canal. Therefore, fixed complete dentures with long posterior cantilevers, an unfavorable biomechanical condition, have to be used.[11]

Tilted implants, an adaptation of the conventional technique, have been used to obtain better anchorage of longer implants, simplify surgery—as grafts are not required—and improve biomechanics as the distal cantilever may be shorter in implant-supported fixed complete dentures.[6]

The biomechanics of clinical rehabilitations with fixed dentures using tilted implants must be clearly understood for treatment success and longevity. Although osseointegrated implants have a high success rate, the results of studies regarding the biomechanical behavior of tilted implants are inconclusive.[18] The present study compared the distribution of stress during treatment using a mandibular implant-supported fixed complete denture, tilted osseointegrated implants, and angled and straight abutments.

Material and Methods

Models of a mandibular full denture and of a resin mandible (Nacional Ossos, Jaú, Brazil) were scanned with a three-dimensional (3D) laser scanner (Nextengine HD, Santa Monica, CA) to produce virtual 3D models. Sixteen circular scannings at 22.5-degree intervals were made for the prosthesis model and 16 for the mandible model. After virtual reconstruction, the 3D models were exported to a CAD tool (Solidworks 2010, Dassault Systemes, Solidworks Corp, Waltham, MA) for the edition of the virtual models. To define the cortical and cancellous bone, peel mill was used to a 2-mm thickness: the external portion was cortical bone, and the internal, cancellous bone. As there is no standard bone thickness, this measure was used to represent a type III bone, which is thin cortical bone according to the classification by Lekholm and Zarb.[17]

For standardization, all implants and abutments were based on SIN products (Sistemas de Implantes, São Paulo, Brazil). When the virtual models were ready, four groups were created according to the following study factors: posterior implants were vertical or tilted, and abutments were straight or angled, according to the following models (Fig 1).

- Model 1. Four parallel vertical implants and straight abutments perpendicular to the bone crest, distributed in the anterior mandible, with the two posterior implants placed 3 mm anterior to the mental foramen.
- Model 2. Similar to model 1, but posterior implants were tilted to 17 degrees, and abutments were straight.
- Model 3. Similar to model 1, but posterior implants were tilted to 17 degrees, and abutments were angled.

Model 4. Similar to model 2, but posterior implants were tilted to 30 degrees, and abutments were straight. Three loading parameters were used in each model — First parameter = occlusal loading of all artificial teeth along the axis of anterior implants (60 N for molars, 40 N for premolars and 20 N for anterior teeth); Second = 135 N at three different points on the same side, one on each posterior tooth, along the axis of anterior implants; Third = same load as for the second parameter, but applied at a 45-degree lingual inclination to the long axis of anterior teeth (Fig 2).

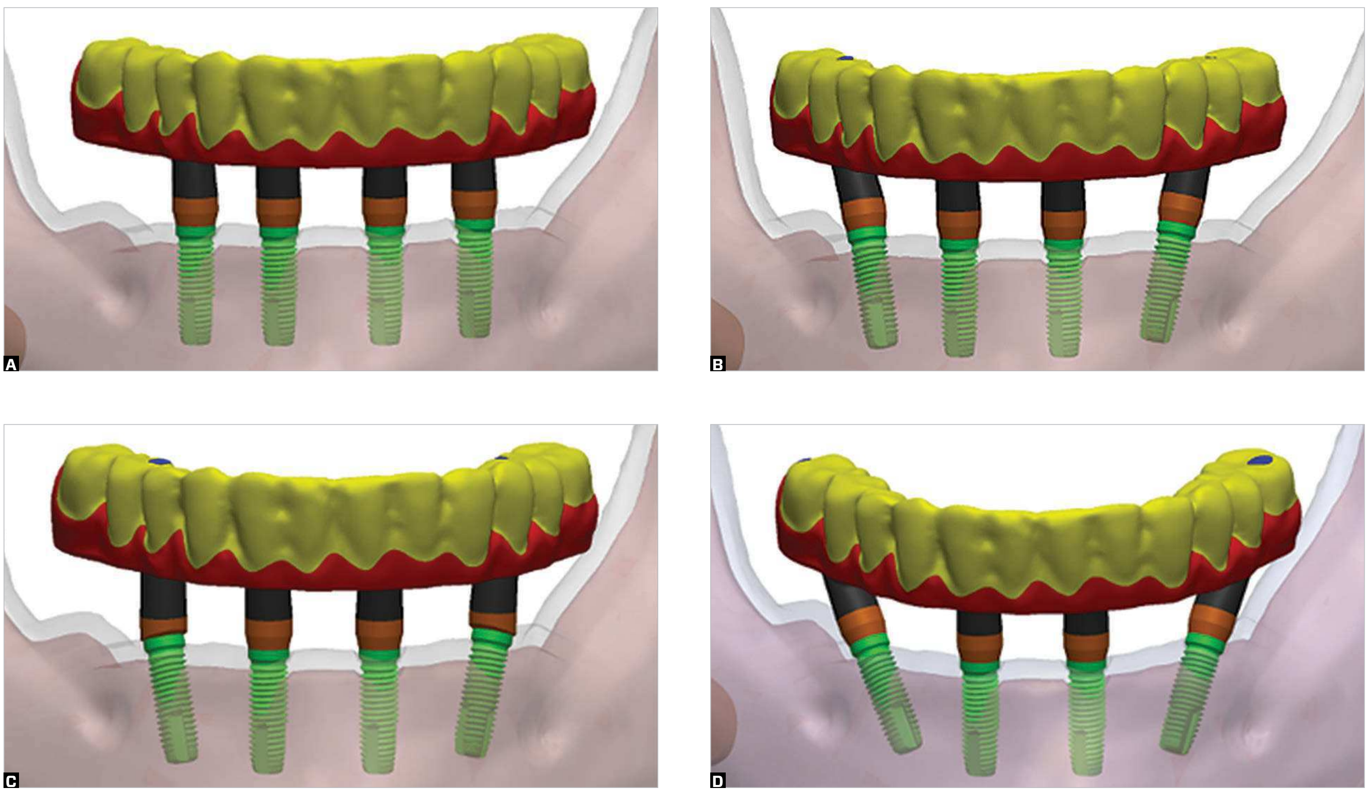

Figure 1 - Different study models; bone is semitransparent for better visualization of implant position: **A**) model 1; **B**) model 2; **C**) model 3; **D**) model 4.

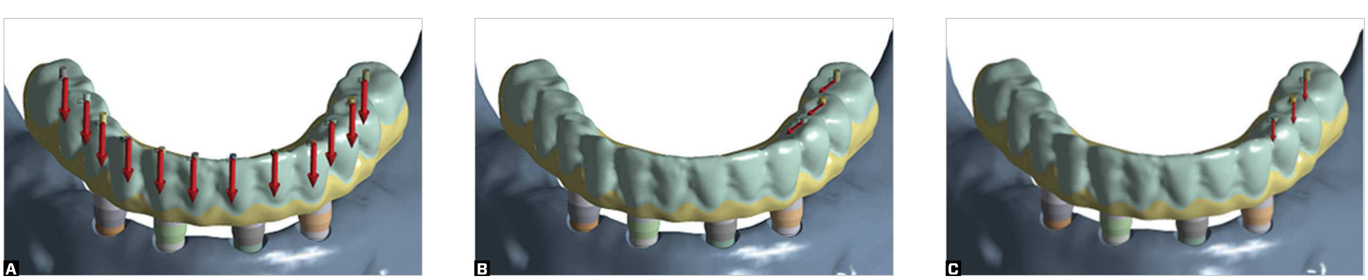

Figure 2 - Loads applied: **A**) axial load on all teeth; **B**) posterior axial load on one side; **C**) posterior off-axis load on one side.

The response criterion was maximum principal stress on metal framework using the Rankine criterion and von Mises stress in bone.

Results

The results of maximum principal stress on the metal framework using Rankine criterion are shown in Table 1. For metal frameworks, posterior implants tilted to 17 degrees had better stress distribution, and stress concentration was higher in the cases of vertical implant placement.

Figures 3, 4 and 5 show maximum principal stress distribution for the three patterns of occlusal loading.

Table 1 - Maximum principal stress peaks on prosthesis framework that received three different loads (in MPa).

	Model 1	Model 2	Model 3	Model 4
Axial load on all teeth	114.15	62.54	68.42	65.43
Posterior axial load on one side	126.26	66.88	71.66	31.73
Posterior off-axis load on one side	146.93	129.18	126.69	91.70

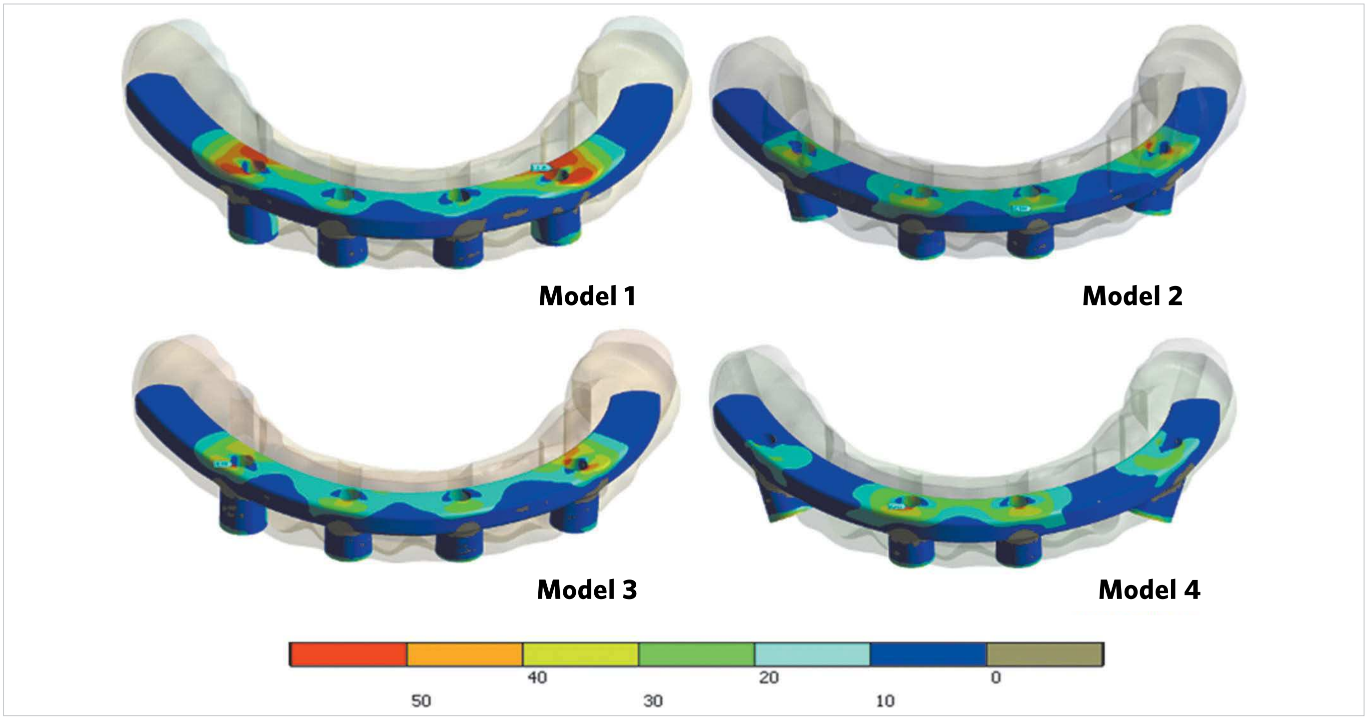

Figure 3 - Maximum principal stress on framework in models 1, 2, 3 and 4 that received axial loads on all teeth. Scale applies to all plots in figure.

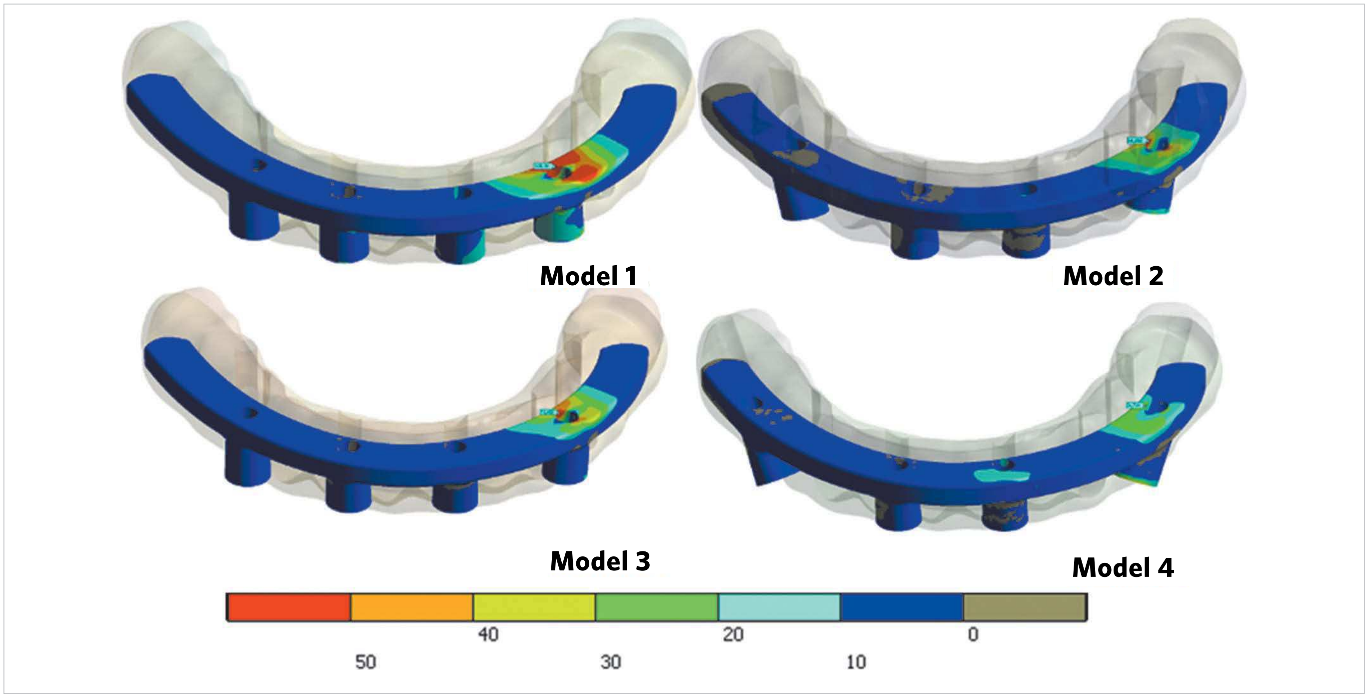

Figure 4 - Maximum principal stress for models 1, 2, 3 and 4 that received posterior axial load on one side. Scale applies to all plots in figure.

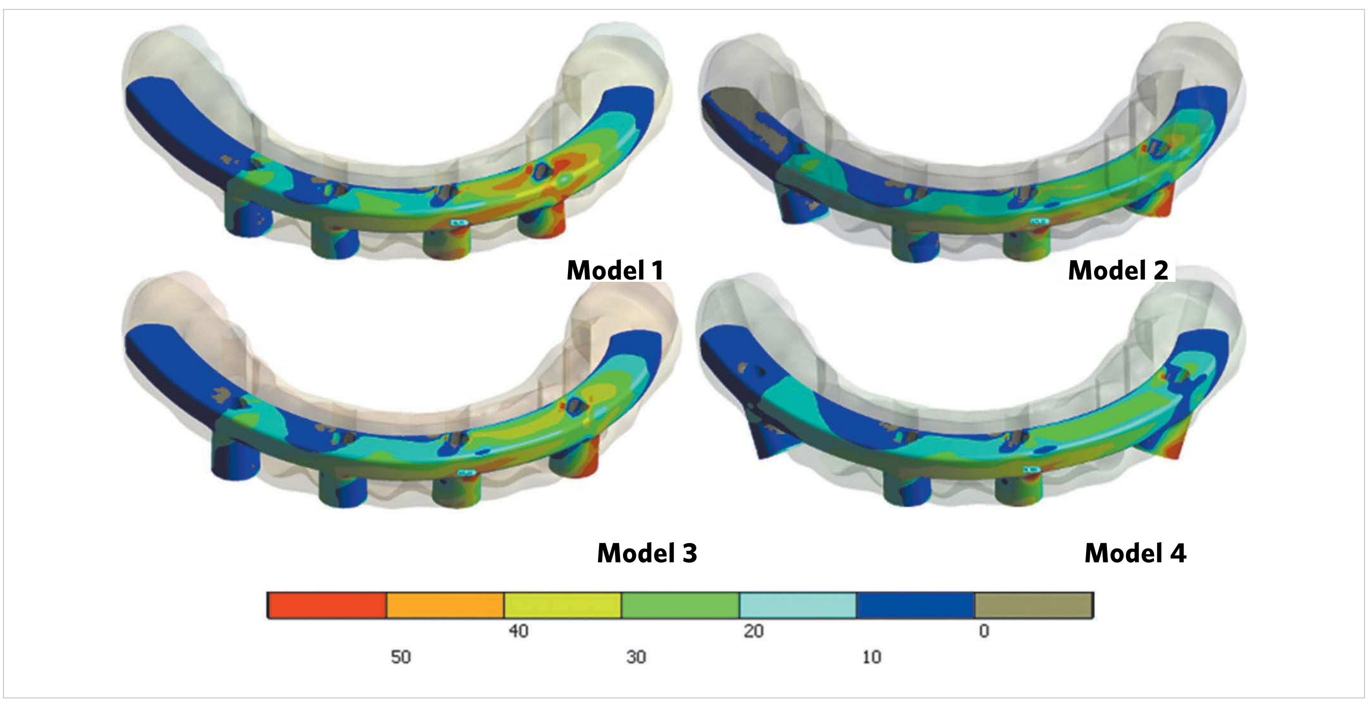

Figure 5 - Maximum principal stress for models 1, 2, 3 and 4 that received posterior off-axis loads on one side. Scale applies to all plots in figure.

Stress distribution on bone in the four models and the three occlusal loading patterns was similar, and stress concentration was higher around the posterior implants than the central implants (Table 2). The evaluation of the posterior implant angles revealed that the 30-degree angle led to a higher concentration of stress on mandibular bone. However, the use of angled abutments did not affect the level of stress on bone around the implants. Figures 6, 7 and 8 show von Mises stress distribution on bone for the three patterns of occlusal loading.

Table 2 - Stress peaks (in MPa) according to von Mises criterion for different models under axial load on all teeth (I); posterior axial load on one side (II); and posterior off-axis load on one side (III).

Implant	Model 1			Model 2			Model 3			Model 4		
	I	II	III	I	II	III	I	II	III	I	II	III
Posterior right side	38.98	4.15	31.2	42.02	6.00	32.31	41.55	6.04	31.16	43.80	6.37	32.68
Anterior right side	17.34	7.79	25.99	24.04	5.06	26.93	20.77	4.24	5.67	25.01	5.67	27.86
Anterior left side	17.95	10.59	30.78	24.47	14.77	28.31	22.51	10.86	26.99	27.84	17.92	28.25
Posterior left side	37.50	37.84	80.81	40.24	41.98	86.88	39.98	40.06	84.95	44.97	45.14	88.87

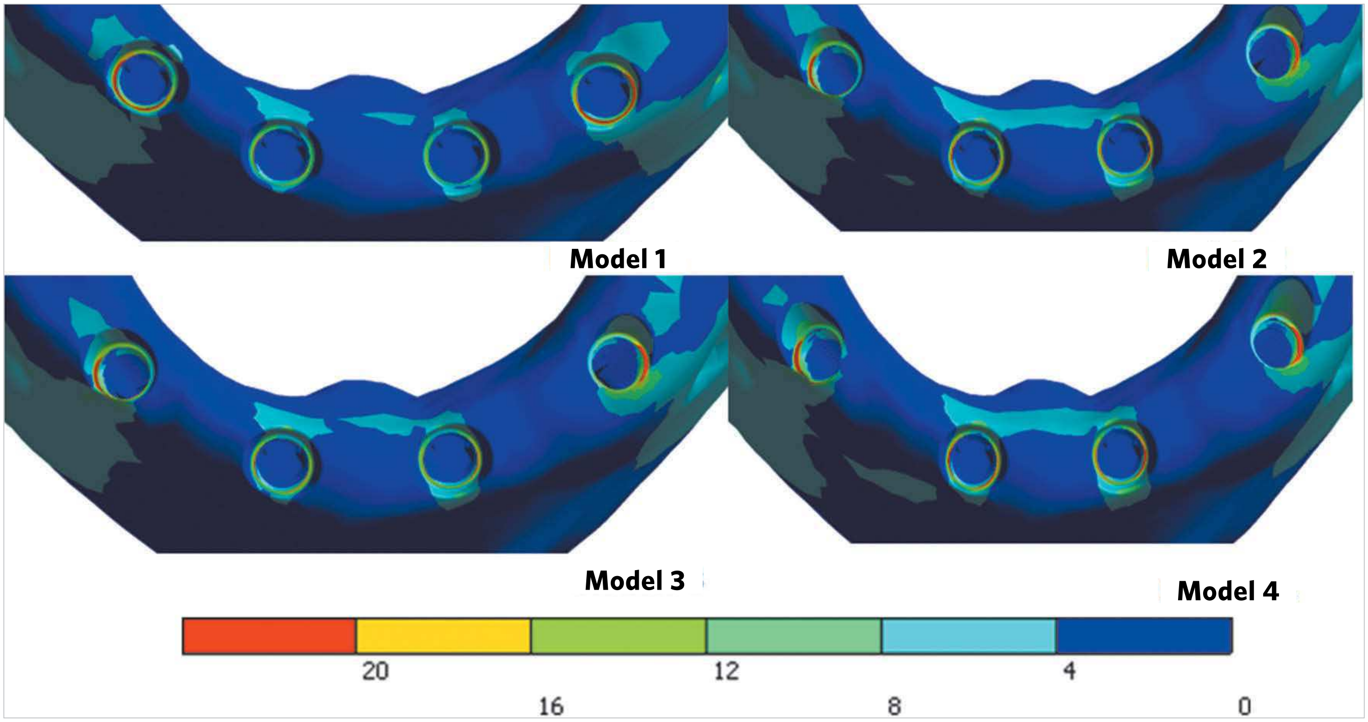

Figure 6 - Von Mises stress for models under axial loading on all teeth; occlusal view. Scale applies to all plots in figure.

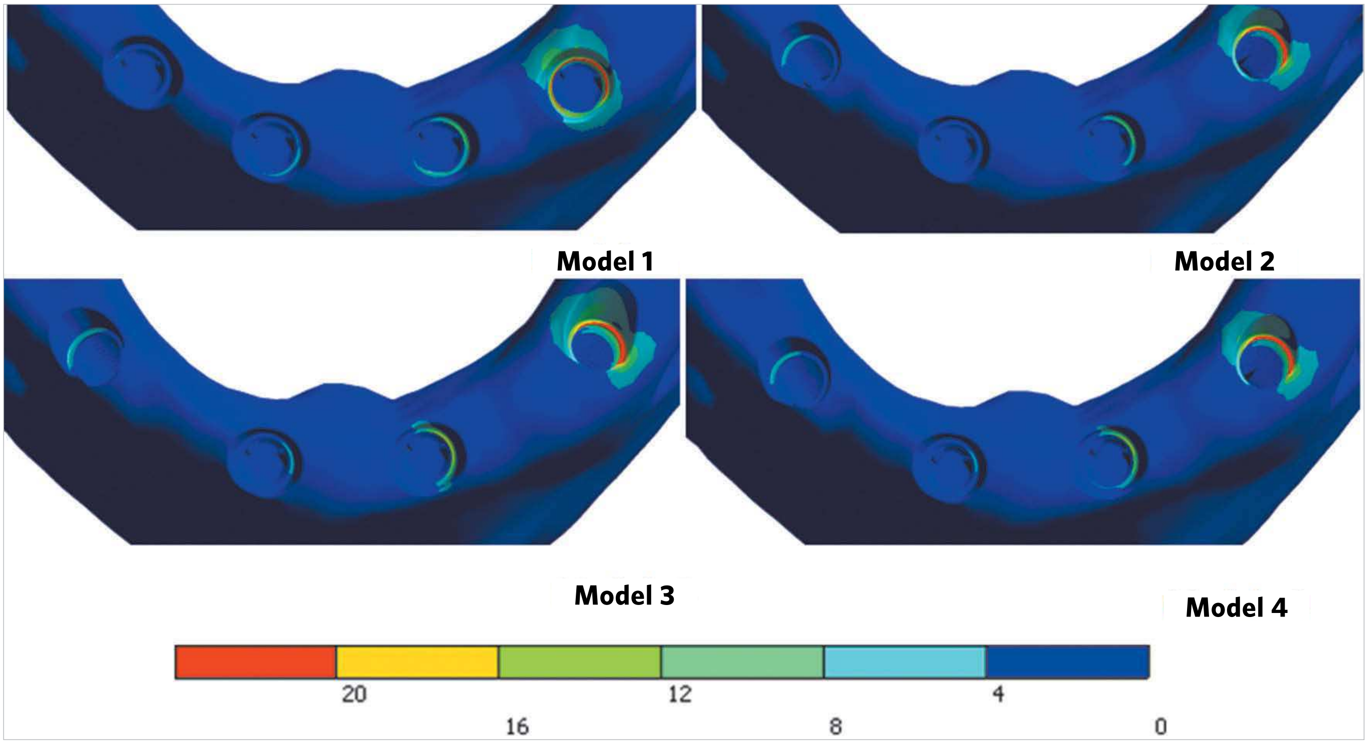

Figure 7 - Von Mises stress for models under posterior axial loading on one side; occlusal view. Scale applies to all plots in figure.

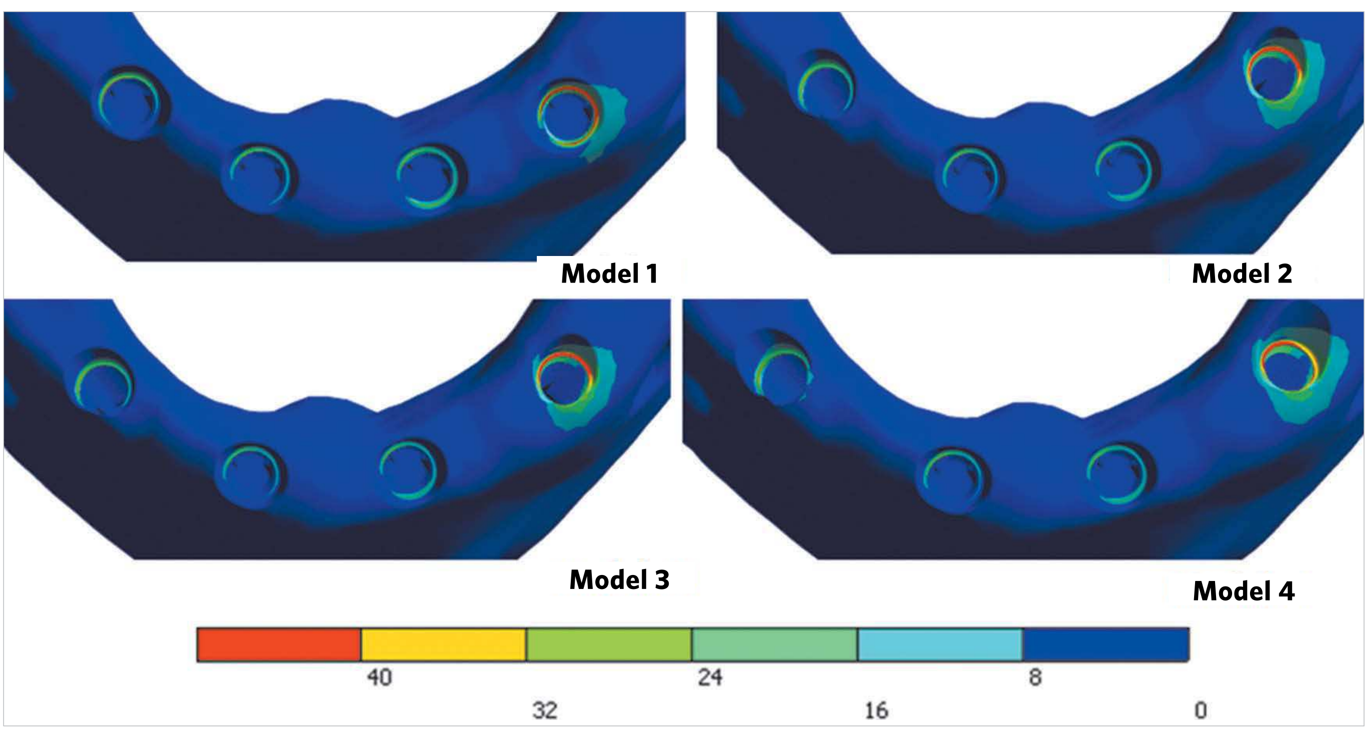

Figure 8 - Von Mises stress for models under posterior off-axis loading on one side; occlusal view. Scale applies to all plots in figure.

Discussion

Studies comparing tilted and nontilted implants have reached a relative consensus.[3,4,7,8,10,12] However, biomechanical evaluations of dentures supported by tilted implants revealed that several studies used different methods.[1,2,9,13,14,20,21]

In studies using finite element analysis, results change according to the method used and, mainly, to the point where force is applied for analysis. Considering the results of the denture that received axial loading on all teeth, we found that model 1 had the highest risk of fracture, with differences from 40 to 45%, which may be explained by the fact that it had the longest cantilever. However, as the cantilever was shortened, the distance between the posterior and anterior supports also increased, which changed the point under fracture risk. When only axial loads in the posterior region were analyzed, the size of the cantilever was proportional to the risk. This is the most predictable condition of all results because of the lever effect of the posterior extension. Under off-axis loading, results were similar, but less marked, probably due to force breakdown. The results on the bone around the implant showed that greater implant angles result in greater stress peaks when loads are applied to all teeth; that is, the vertical position of the implant favors stress distribution to a larger area and reduces stress concentration. Therefore, implant angle increases the risk of implant loss in dentures that receive loads on all teeth.

In 2009 Bellini et al[5] used a similar method to evaluate models with 4 and 5 interforaminal implants where posterior implants had a 30-degree inclination and the prosthesis had a 5 or 15 mm cantilever. They also found greater stress concentration on tilted implants, which confirms our results.

In a study conducted by Bevilacqua et al[6], four implants were placed in the maxilla at inclinations of 0, 15, 30 and 45 degrees, and the length of the prosthesis was constant, as in our study. However, differently from our results, tilted posterior implants produced less stress concentration on bone around the implants, which may be explained by the different points of load application in the posterior region.

In a study conducted by Silva et al,[23] finite element analysis was used to compare the distribution of stress on maxillary fixed dentures supported by 4 and 6 implants, and with posterior implants placed at an angle of 45 degrees. They found that the presence of a cantilever significantly increased the levels of stress on the implant-prosthesis unit, which confirms the results reported here.

Conclusions

After the analysis of the framework of the prosthesis and loading according to the conditions used for the models in this study, the results of our simulations suggest that the model with vertical implants had the highest risk of fracture and that the highest degree of distal inclination of the posterior implants (30 degrees) promoted stress concentration on bone around the implant and, consequently, increased the risk of bone loss around the implants.

REFERENCES

1. Agliard E, Francetti L, Romeo D, Deo Fabro M. Immediate loading in the fully edentulous maxilla without bone grafting: the V-II-V technique. Minerva Stomatol. 2008;57(5):251-63.
2. Agliard E, Panigatti S, Clericò M, Villa C, Malò P. Immediate rehabilitation of the edentulous jaws whit full fixed protheses supported by four implants: interim results of a single cohort prospective study. Clin Oral Implants Res. 2010;21:459-65.
3. Aparicio C, Perales P, Rangert B. Tilted implants as an alternative to maxillary sinus grafting: a clinical, radiologic, and periotest study. Clin Implant Dent Relat Res. 2001;3(1):39-49.
4. Bateli M, Woemer W. Tilted implants to support a maxillary removable dental prosthesis: a case report. Quintessence Int. 2012;43(3):191-5.
5. Bellini CM, Romeo D, Galbusera F, Taschieri S, Raimondi MT, Zampelis A, et al. Comparison of tilted versus nontilted implant-supported prosthetic designs for the restoration of the edentulous mandible: a biomechanical study. Int J Oral Maxillofac Implants. 2009;24(3):511-7.
6. Bevilacqua M, Tealdo T, Menini M, Pera F, Mossolov A, Drago C, et al. The influence of cantilever length and implant inclination on stress distribution in maxillary implant-supported fixed dentures. J Prosthet Dent. 2011;105(1):5-13.
7. Capelli M, Zuffetti F, Fabbro MD, Testori T. Immediate rehabilitation of the completely edentulous jaw with fixed prostheses supported by either upright or tilted implants: a multicenter clinical study. Int J Oral Maxillofac Implants. 2007;22(4):639-64.
8. Crespi R, Vinci R, Capaaré P, Romanos G, Gherlone E. A clinical study of edentulous patients rehabilitated according to the "all on four" immediate function protocol. Int J Oral Maxillofac Implants. 2012;27(2):428-34.
9. Degidi M, Nardi D, Piattelli A. Immediate loading of the edentulous maxilla with a definitive restoration supported by an intraorally welded titanium bar and tilted implants. Int J Oral Maxillofac Implants. 2010;25(6):1175-82.
10. Del Fabbro M, Testori T, Francetti L, Weinstein RL. Systematic review of survival rates for implants placed in grafted maxillary sinus. Int J Periodontics Restorative Dent. 2004;24(6):565-77.
11. Fazi G, Tellini S, Vangi D, Branchi R. Three-dimensional finite element analysis of different implant configurations for a mandibular fixed prosthesis. Int J Oral Maxillofac Implants. 2011;26(4):752-9.
12. Fortin T, Isidori M, Bouchet H. Placement of maxillary implants in partially edentulous patients with severe bone deficiency using cad/can guidance to avoid sinus grafting: a clinical report of procedure. Int J Oral Maxillofac Implants. 2009;24(1):96-102.
13. Galindo D, Butura C. Immediately loaded mandibular fixed implant prostheses using the all-on-four protocol: a report of 183 consecutively treated patients with 1 year of function in definitive prostheses. Int J Oral Maxillofac Implants. 2012;27(3):628-33.
14. Hinze M, Thalmair T, Bolz W, Wachtel H. Immediate loading of fixed provisional prostheses using four implants for the rehabilitation of the edentulous arch: a prospective clinical study. Int J Oral Maxillofac Implants. 2010;25(5):1011-8.
15. Kim KS, Kim YL, Bae JM, Cho HW. Biomechanical comparison of axial and tilted implants for mandibular full-arch fixed prosthesis. Int J Oral Maxillofac Implants. 2011 Sep;26(5):976-84.
16. Koutouzis T, Wennström JL. Bone level changes at axial- and non-axial-positioned implants supporting fixed partial dentures. A 5-year retrospective longitudinal study. Clin Oral Implants Res. 2006;18(5):585-90.
17. Lekholm U, Zarb FL. Patient selection and preparation. Tissue integrated prostheses: osseointegration in clinical dentistry. Chicago: Quintessence; 1985.
18. Naini RB, Nokar S, Borghei H, Alikhasi M. Tilted or parallel implant placement in the completely edentulous mandible? A three-dimensional finite element analysis. Int J Oral Maxillofac Implants. 2011;26(4):776-81.
19. Ogawa T, Dhaliwal S, Naert I, Mine A, Kronstrom M, Sasaki K, et al. Impact of implant number, distribution and prosthesis material on loading on implants supporting fixed prostheses. J Oral Rehabil. 2010;37(7):525-31.
20. Peñarrocha M, Carrillo C, Boronat A, Peñarrocha M. Maximum use of the anterior maxillary buttress in severe maxillary atrophy with tilted, palatally positioned implants: a preliminary study. Int J Oral Maxillofac Implants. 2010;25(4):813-20.
21. Peñarrocha-Oltra, D Ata-Ali J, Candel-Marti ME, Peñarrocha-Diago MA. Oral rehabilitation with tilted dental implants: a metaanalysis. Med Oral Patol Oral Cir Bucal. 2012;17(4):e582-7.
22. Sadrimanesh R, Siadat H, Sadr-Eshkevari P, Monzavi A, Maurer P, Rashad A. Alveolar bone stress around implants with different abutment angulation: an FE-analysis of anterior maxilla. Implant Dent. 2012;21(3):196-201.
23. Silva GC, Mendonça JA, Lopes LR, Landre Junior J. Stress patterns on implants in protheses supported by four or six implants: a three-dimensional finite element analysis. Int J Oral Maxillofac Implants. 2010;25(2):239-46.
24. Testori T, Del Fabbro M, Capelli M, Zuffetti F, Francetti L, Weinstein RL. Immediate occlusal loading and tilted implants for the rehabilitation of the atrophic edentulous maxilla: 1-year interim results of a multicenter prospective study. J Prosthet Dent. 2008;99(3):167.