Tilted and Short Implants Supporting Fixed Prosthesis in an Atrophic Maxilla: A 3D-FEA Biomechanical Evaluation

Erika O. Almeida, DDS, PhD;* Eduardo P. Rocha, DDS, PhD;† Amilcar C. Freitas Júnior, DDS, PhD;‡ Rodolfo B. Anchieta, DDS, MSc;§ Ronald Poveda, MS;¶ Nikhil Gupta, PhD;** Paulo G. Coelho, DDS, PhD††

ABSTRACT

Purpose: This study compared the biomechanical behavior of tilted long implant and vertical short implants to support fixed prosthesis in an atrophic maxilla.

Materials and Methods: The maxilla model was built based on a tomographic image of the patient. Implant models were based on micro-computer tomography imaging of implants. The different configurations considered were M4S, four vertical anterior implants; M4T, two mesial vertical implants and two distal tilted (45°) implants in the anterior region of the maxilla; and M6S, four vertical anterior implants and two vertical posterior implants. Numerical simulation was carried out under bilateral 150 N loads applied in the cantilever region in axial (L1) and oblique (45°) (L2) direction. Bone was analyzed using the maximum and minimum principal stress (σ_{max} and σ_{min}), and von Mises stress (σ_{vM}) assessments. Implants were analyzed using the σ_{vM}.

Results: The higher σ_{max} was observed at: M4T, followed by M6S/L1, M6S/L2, M4S/L2, and M4S/L1 and the higher σ_{vM}: M4T/L1, M4T/L2 and M4S/L2, M6S/L2, M4S/L1, and M6S/L1.

Conclusions: The presence of distal tilted (*all-on-four*) and distal short implants (*all-on-six*) resulted in higher stresses in both situations in the maxillary bone in comparison to the presence of vertical implants (*all-on-four*).

KEY WORDS: biomechanics, dental implants, finite element analysis, osseointegration

INTRODUCTION

Implant rehabilitation in atrophic maxilla has been considered a prosthetic and surgical challenge due to the small quantity and low quality of bone, usually represented by bone type III and IV,[1] and anatomic constraints such as presence of the nasal fossa along with the frequent need of maxillary sinus augmentation.[2,3] The potential for such complex scenarios may severely restrict the number, length, width, and position of the implants that are to be used, affecting the final prosthetic design.[4] The challenge of implant placement in the posterior region may also result in the long cantilevered prosthesis, increasing the risk of implant biomechanical failure.[5–8] Thus, careful treatment planning is necessary for the successful treatment of such implant-supported prosthesis.

The use of bone grafting and sinus elevation has been an alternative in improving the implant placement

*Professor, Department of Dentistry, Federal University of Rio Grande do Norte, Natal, RN, Brazil; †assistant professor, Department of Dental Material and Prosthodontics, Sao Paulo State University Aracatuba School of Dentistry, Sao Paulo, SP, Brazil; ‡associate professor, Postgraduate Program in Dentistry, Potiguar University School of Dentistry, Natal, RN, Brazil; §PhD student, Department of Dental Material and Prosthodontics, Sao Paulo State University Aracatuba School of Dentistry, Sao Paulo, SP, Brazil, and visiting scholar, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, NY, USA; ¶PhD student, Department of Mechanical and Aerospace Engineering, Polytechnic Institute of New York University, New York, NY, USA; **associate professor, Department of Mechanical and Aerospace Engineering, Polytechnic Institute of New York University, New York, NY, USA; ††assistant professor, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, NY, USA

Reprint requests: Prof. Erika O. Almeida, 1787 Sen. Salgado Filho, Lagoa Nova, Natal – RN 58056-000, Brazil; e-mail: erika.almeida.protese@gmail.com

No conflict of interest.

DOI 10.1111/cid.12129

location and the overall mechanical behavior of prosthesis by allowing implant placement in posterior regions.[8–10] However, the invasive nature of the surgical procedure associated with the increased risk of morbidity, high costs, and time required for treatment completion are the commonly cited drawbacks.[2,11] While a wide range of survival rates has been reported (from 70% to 95%), these are mainly due to postoperative graft complications such as infections and host site morbidity.[10,12] Also reported are difficulties in restoring and maintaining esthetic appearance due to graft resorption over time.[13]

The use of tilted or short implants in the maxilla has been demonstrated to be alternatives to bone grafting, increasing patient acceptance toward implant-supported oral rehabilitation.[2,7,14–17] Although several studies have reported that rehabilitation utilizing short implants may be regarded as a reliable treatment,[18–23] it is not yet clear whether the utilization of short implants toward the posterior region or tilted implants in the anterior region are best in cases where limited bone height is present in molar regions. By tilting the distal implant toward the anterior in the *all-on-four* concept, a more posterior implant position may be reached, potentially improving implant anchorage through the cortical bone of the wall of the sinus and the nasal fossa.[24–27] From a biomechanical perspective, laboratory studies on models and theoretical calculations have indicated that tilted implants, primarily due to bending, may increase the stress in the surrounding bone.[28–30] These studies were performed on single implants or linear arrangements. In multiple implant-supported prosthetic restorations, the spread of the implants and rigidity of the prosthesis will reduce bending of the implants. The bending magnitude may be larger in single-unit treatment modalities, potentially resulting in pronounced bone resorption.[29] Previous studies have reported that when the posterior implant is tilting, no difference in bone resorption relative to a vertical implant was observed.[2,24]

Although the use of only four implants for a complete fixed rehabilitation of the maxilla has been supported by clinical studies at short period,[24,31,32] it has been suggested that using a larger number of implants (around 6) for prosthetic treatment of the edentulous maxilla may be beneficial.[1,29,33–36] The number of implants and their respective configurations for implant-supported treatment modalities have been studied; however, it is not yet clear whether the use of tilting or short implants in rehabilitation would result in substantially improved bone/implant/prosthesis biomechanics.

Thus, using a tridimensional finite element analysis method, this study compared the biomechanical behavior of tilted long implant (*all-on-four*, *2 vertical mesial implants*, and *2 distal tilted implants*) and vertical short implants (*all-on-six*, *4 anterior vertical implants*, *and 2 posterior short implants*) to support fixed prosthesis in an atrophic maxilla. The hypotheses of the present study were that the presence of distal tilted (*all-on-four*) and distal short implants (*all-on-six*) would respectively result in higher and lower stresses in the maxillary bone in comparison to the presence of vertical implants (*all-on-four*).

MATERIALS AND METHODS

Geometric Reconstruction

Three geometrical models were constructed based on the tomographic image of a patient (Aracatuba College of Dentistry Ethical Comite # 01686/09) and on micro-computer tomography (micro-CT) of the implants (Nobel Speed™ RP and Branemark System MkIII WP, Nobel Biocare, Yorba Linda, CA, USA) and respective abutments (Table 1). The selected patient showed an atrophic maxilla with a moderate maxillary sinus pneumatization. The scan was carried out by a Galileos Conic Tomography (Sirona, Bensheim, Germany) with a voxel dimension of 0.3 mm, voltage level of 85 kV with a current of 42 mAs and exposure time of 14 s for 200 slices. The implants connected to straight or tilted (30°) abutments (Table 1) were scanned with a micro-CT (Scanco Medical 40, Bassersdorf, Switzerland) with an X-ray energy level of 70 kVp with a current of 114 μA.[37] The integration time was 300, the stepping rotational angle was 0.18 degrees[37] and each implant with abutment presented approximately 800 slices that were used in the reconstruction. For both maxilla and implant components, the *dicom* files were imported in the ScanIP software (Simpleware, Exeter, UK) in order to generate the 3D-CAD model based on the image density thresholding.[38] Each mask presented a cubic resampling of 0.18 mm (pixel spacing in X, Y, and Z) with linear image interpolation method. The maxilla dimensions were 84 mm (X, width), 71 mm (Y, length), and 19 mm (Z, height) (Figure 1A–E). The *.stl* files were exported to ScanCAD (Simpleware) to generate the assembly of

TABLE 1 Model Descriptions for the Present Study

Models	Implant No.	Implant Inclination	Region of Anchorage	Implants	Multi-Unit Abutments
M4S	4	0°	Nasal cavity	Nobel Speed Groovy RP 4.0 X 11.5 mm	Straight 4.0 mm RP
			Canine pillar	Nobel Speed Groovy RP 4.0 X 13 mm	
M4T	4	0°	Nasal cavity	Nobel Speed Groovy RP 4.0 X 11.5 mm	Straight 4.0 mm RP
		45°	Canine pillar	Nobel Speed Groovy RP 4.0 X 13 mm	30° non-engaging 4.0 m RP (All-on-four)
M6S	6	0°	Nasal cavity and canine pillar	Nobel Speed Groovy RP 4.0 X 11.5 mm	Straight 4.0 mm
				Nobel Speed Groovy RP 4.0 X 13 mm	
			Tuber	Branemark System Mk III Short WP 5.0 X 7.0 mm	

M4S = model with four vertical implants; M4T = model with four implants with the tilted distal; M6S = model with six vertical implants; MI = mesial implants; DI = distal implants.

the structures using the "masking technique"[38] to construct models based on different configurations in the atrophic maxilla using implants to support a fixed prosthesis: M4S – four implants (mesial – 4 mm in diameter and 11.5 mm in length; distal – 4 mm in diameter and 13 mm in length, respectively) were placed bilaterally vertically in the anterior region of the maxilla (Figure 2A and D); M4T – two mesial implants (4 mm in diameter and 11.5 mm in length) were placed vertically and two distal implants (4 mm in diameter and 13 mm in length) were tilted at a 45-degree angle toward the anterior region of the maxilla (Figure 2B and E); M6S – four implants (mesial – 4 mm in diameter and 11.5 mm in length; distal – 4 mm in diameter and 13 mm in length) were placed vertically in the anterior region of the maxilla and two short implants (5 in diameter and 7 mm in length) were placed vertically in the posterior region (Figure 2C and F). Detailed information concerning implant position are presented in Table 1 and Figure 2A–F.

The models (M4S, M4T, and M6S) were exported back to the ScanIP software where the implants in each model were splinted with a rigid titanium bar with the dimensions of 5.8 mm in thickness and 4 mm in height (Figure 2D–F). The *all-on-four* planning (M4S and M4T) presented a 14-mm-long distal cantilever in the right side and an 18-mm-long in the left side (Figure 2D and E), whereas the M6S presented a 2-mm-short cantilever (Figure 2F). Segmentation was used to design the bars with the same numbers of slices for each model. The distance from the bar to the maxilla was maintained constant for all models (Figure 2A–F). For this reason, different implants presented varied insertion depth in bone. A squared loading area was bilaterally placed in the first molar region for each model at the same numbers of slices and the same position (Figure 2D–F).

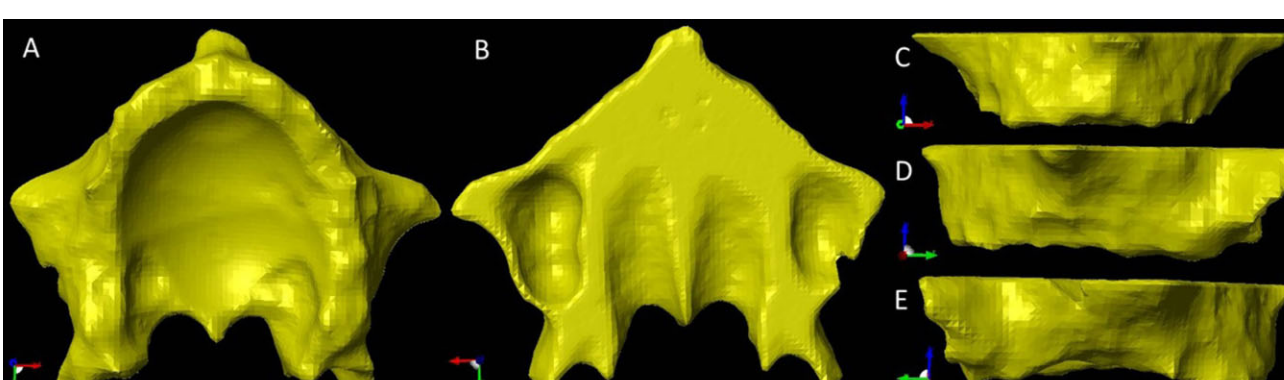

Figure 1 Tridimensional CAD of the maxilla in the inferior (A), superior (B), frontal (C), lateral left (D), and lateral right (E). The red, green, and blue arrows indicate X, Y, and Z direction.

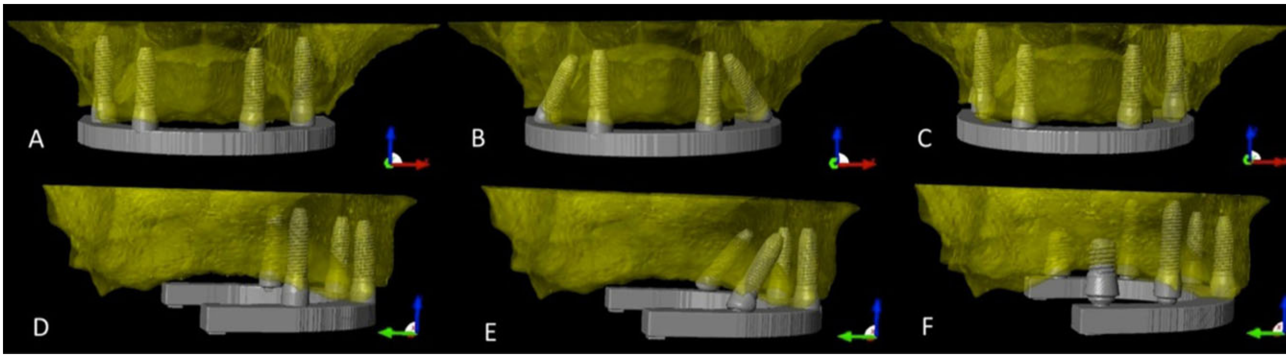

Figure 2 Frontal (A–C) and lateral right (D–F) view of the models M4S (A and D), M4T (B and E) and M6S (C and F). The red, green, and blue arrows indicate X, Y, and Z direction.

Finite Element Modeling

Using the ScanIP software, the implants were subtracted from the maxilla and the bar using Boolean operations. The mechanical properties (elastic modulus and Poisson's ratio) were defined for each material derived from biomechanical studies simulating trabecular type III bone (Table 2).[33,39,40] The models presented linear elastic characteristics.[41] The different model components were assumed to be homogenous, isotropic[41] and perfectly connected (bonded). The mesh set up used pre-smoothing with 100 iterations allowing all parts change with higher quality optimization. The volume meshing was edited to use adaptive surface remeshing with target minimum edge length 0.09 mm, target maximum error of 0.045 mm,and maximum edge length of 5.0 mm. The number of tetrahedral volume elements in each model was 295252 (M4S), 229919 (M4T), and 445120 (M6S; Figure 3A–F). The FE models were exported as Ansys volume (solid/shells) to Ansys 13 software (Ansys Inc., Canonsburg, PA, USA) for the analysis.

In Ansys 13, two load directions were bilaterally applied (150 N): L1 – axial (Figure 4A and B) and L2 – oblique (45°) in the buccal-lingual direction (Figure 4A and C) in the area corresponding to the first molar region. The boundary conditions of the model were defined according to the union of the maxilla to the base of the skull, by which six degrees of freedom were constrained (Figure 4B and C).[42]

The maximum and minimum principal stresses (σ_{max} and σ_{min}) were selected as stress output for the maxilla in order to allow distinction between tensile and compressive stress.[43,44] For ductile materials such as implants, von Mises stress (σ_{vM}) output was adopted for descriptive statistical analysis.[45] The implants and bone

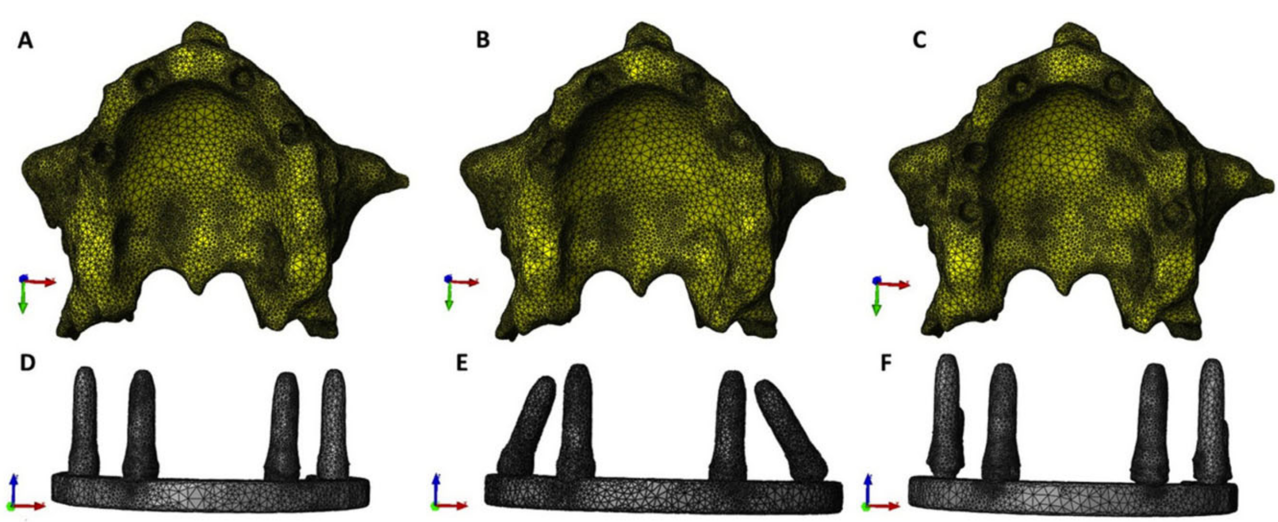

Figure 3 Finite element mesh of the M4S (A and D), M4T (B and E), and M6S (C and F).

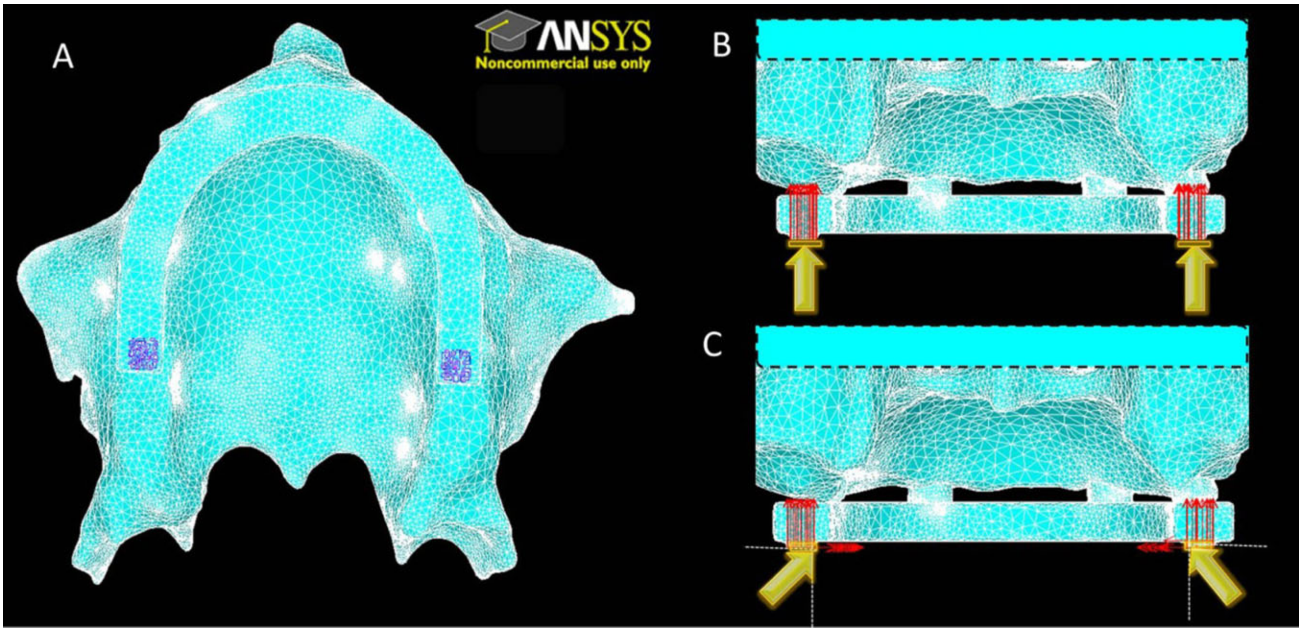

Figure 4 Loading area bilaterally at the bar cantilever (A). Axial – L1 (B) and oblique – L2 (C) loading in Ansys Software. Boundary condition include displacement at the top surface (identified by dotted bl) of the maxilla for axial (L1) and oblique (L2) loading. (B and C).

around implants were numbered from 1 (left side) to 4/6 (right side) for evaluation (Figure 5A–C).

RESULTS

Comparing the results of the three different implant treatment configuration (M4S, M4T, and M6S) for the atrophic maxilla in the axial and oblique loading conditions (L1 and L2), the maximum principal stress in bone (σ_{max}) was highest for the M4T (L1 0.87 and L2 0.85 GPa), followed by M6S/L1 (0.71 GPa), M6S/L2 (0.61 GPa), M4S/L2 (0.44 GPa), and M4S/L1 (0.26 GPa; Table 3; Figure 6). Concerning the angular orientation of implants in the M4T (tilted) configuration, these presented 70% and 48% higher stress in bone compared to the M4S (vertical) when both axial and oblique loading were applied. Relative to the number of implants, the M6S configuration presented 63% and 27% higher stress in bone compared to M4S (4 implants) when the axial and oblique loadings were applied, mainly because of different insertion depths of the implant 6. The maximum values of each model were visualized around implant 1 (M4S/L1; M4T/L2; M4S/L2), 2 (M4T/L1), and 6 (M6S/ L1 and L2; Table 3; Figure 6).

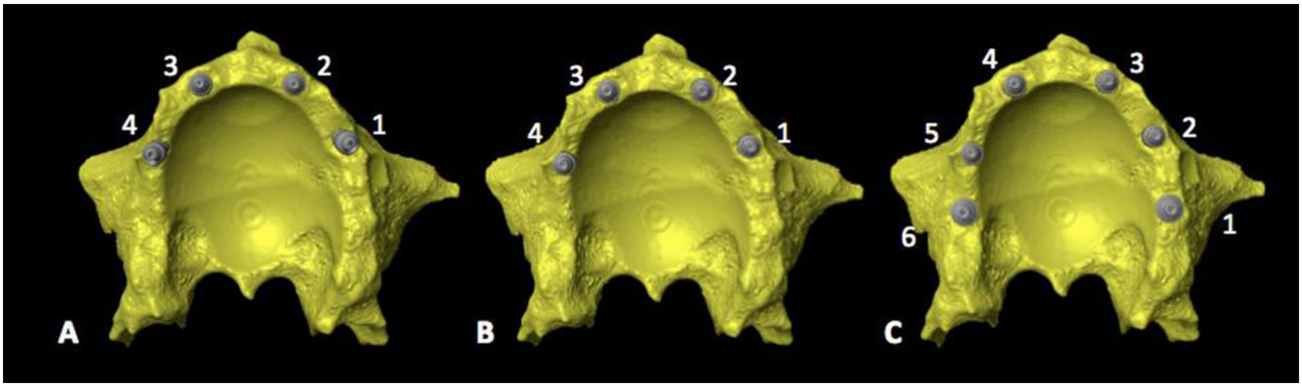

Figure 5 Occlusal view of the implants in the M4T (A), M4S (B), and M6S (C) planning. The numbers 1 to 4 (M4T and M4S) and 1 to 6 (M6S) represent the implant numbers in each model for evaluation. The all-on-four configuration (M4I and M4S) shows the cantilever in the right and left side.

TABLE 2 Mechanical Properties of the Components Assigned in FEA

Material	Elastic Modulus (E) (GPa)	Poisson Ratio (v)	References
Cortical bone	13.8	0.26	Huang et al. (2008)[40]
Trabecular bone Type III	1.60	0.30	de Almeida et al. (2010)[39]
Titanium	110	0.35	de Almeida et al. (2010)[39]

For the axial loading (L1), the minimum principal stress (σ_{min}) was lower for the M6S (–0.03 GPa), followed by M4S (–0.09 GPa), and M4T (–0.23 GPa). For the oblique loading (L2), the σ_{min} was lower for M6S (–0.09 GPa), followed by M4S (–0.1 GPa) and M4T (–0.24 GPa). The σ_{min} of each model were visualized around implant 2 for all situations, except for M6S/L2 that the minimum was visualized around implant 4 (Table 3).

TABLE 3 Stress Values (GPa) in Bone for Axial (L1) and Oblique (L2) Loading in the M4T, M4S, and M6S Models. The Maximum and Minimum Principal Stresses (σ_{max} and σ_{min}) Were Adopted for Bone

Models	σ_{max} (1)	σ_{min} (1)	σ_{max} (2)	σ_{min} (2)	σ_{max} (3)	σ_{min} (3)	σ_{max} (4)	σ_{min} (4)	σ_{max} (5)	σ_{min} (5)	σ_{max} (6)	σ_{min} (6)
M4T (L1)	0.71	−2.45	0.87	−0.23	0.65	−0.49	0.32	−2.08	X	X	X	X
M4S (L1)	0.26	−0.50	0.37	−0.09	0.59	−0.17	0.15	0.74	X	X	X	X
M6S (L1)	0.09	−0.32	0.03	−0.03	0.06	−0.04	0.07	−0.04	0.03	−0.05	0.71	−0.32
M4T (L2)	0.85	−1.96	0.73	−0.24	0.45	−0.31	0.30	−1.82	X	X	X	X
M4S (L2)	0.44	−0.62	0.30	−0.10	0.36	−0.16	0.34	−0.93	X	X	X	X
M6S (L2)	0.44	−0.62	0.08	−0.12	0.04	−0.16	0.06	−0.09	0.07	−0.11	0.61	−0.50

(1–6) Stress values on bone around Implant 1 (1), 2 (2), 3 (3), 4 (4), 5 (5), and 6 (6); M4S = model with four vertical implants; M4T = model with four implants with the tilted distal; M6S = model with six vertical implants.

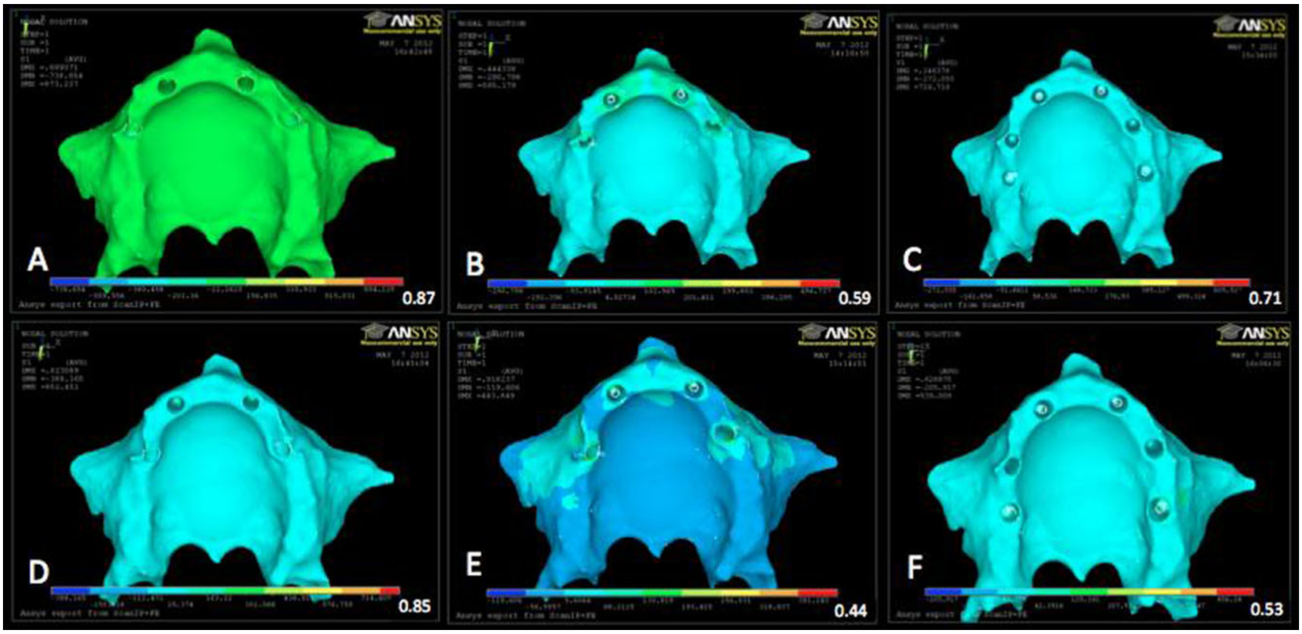

Figure 6 Maximum principal stress (σmax) (GPa) in the axial (L1) and oblique (L2) loading for M4T (A and D), M4S (B and E), and M6S (C and F). The maximum values of each model were visualized around implant 1 – M4S/L1 (B), M4T/L2 (D), and M4S/L2 (E); implant 2 – M4T/L1 (A) and implant 6 – M6S/ L1 (C) and L2 (F).

TABLE 4 Stress Values (GPa) in Bone and Implants for Axial (L1) and Oblique (L2) Loading in the M4T, M4S, and M6S Models. The von Mises Stress (σ_{vM}) Was Adopted for Bone and Implants for Comparison

Model	σ_{vM} (1)	σ_{vM} (2)	σ_{vM} (3)	σ_{vM} (4)	σ_{vM} (5)	σ_{vM} (6)	IMP 1 σ_{vM}	IMP 2 σ_{vM}	IMP 3 σ_{Vm}	IMP 4 σ_{vM}	IMP 5 σ_{vM}	IMP 6 σ_{vM}
M4T (L1)	2.01	0.71	0.45	1.32	X	X	49.4	5.5	4.1	34.1	X	X
M4S (L1)	0.38	0.32	0.53	0.45	X	X	33.6	11.2	7.5	36.4	X	X
M6S (L1)	0.2	0.02	0.05	0.05	0.03	0.2	5.6	0.4	0.8	1.3	0.5	61
M4T (L2)	0.85	0.73	0.45	0.3	X	X	41.8	7.2	6.5	30.7	X	X
M4S (L2)	0.60	0.27	0.33	0.85	X	X	33.1	12.1	14.2	38.5	X	X
M6S (L2)	0.54	0.09	0.13	0.08	0.12	0.50	5.6	1.6	2.4	3.4	1.6	49.1

(1–6) Stress values on bone around implant 1 (1), 2 (2), 3 (3), 4 (4), 5 (5), and 6 (6); IMP = implant; M4S = model with four vertical implants; M4T = model with four implants with the tilted distal; M6S = model with six vertical implants.

Considering the σ_{vM} stress in the bone for comparison to the stress (σ_{vM}) in the implant, the maximum values was higher for M4T/L1, followed by M4T/L2 and M4S/L2 (0.85 GPa), M6S/L2 (0.54 GPa), M4S/L1 (0.53 GPa), and M6S/L1 (0.2 GPa). Concerning the angular orientation of implants in the M4T (tilted) configuration, these presented 73% higher stresses in bone compared to the M4S (vertical) when the axial loading was applied. Contradictorily, when the oblique loading was applied, there was no difference between the two models. Relative to the number of implants, the M4S configuration presented 62% and 60% higher stress in bone compared to M6S when the axial and oblique loadings were applied. The maximum values of each model were visualized around implant 1 (M4T/L1 and L2, M6S/L2), 3 (M4S/L1), 4 (M4S/L2), and the M6S/L1 showed the maximum values around implants 1 and 6 (Table 4; Figure 7).

The σ_{vM} stress in the implant was higher in the M4T model, were the highest stress value of L1, and L2 were observed at implant number 1 (49.4 and 41.8 GPa, respectively), followed by implant 4 (34.1 and 30.7 GPa),

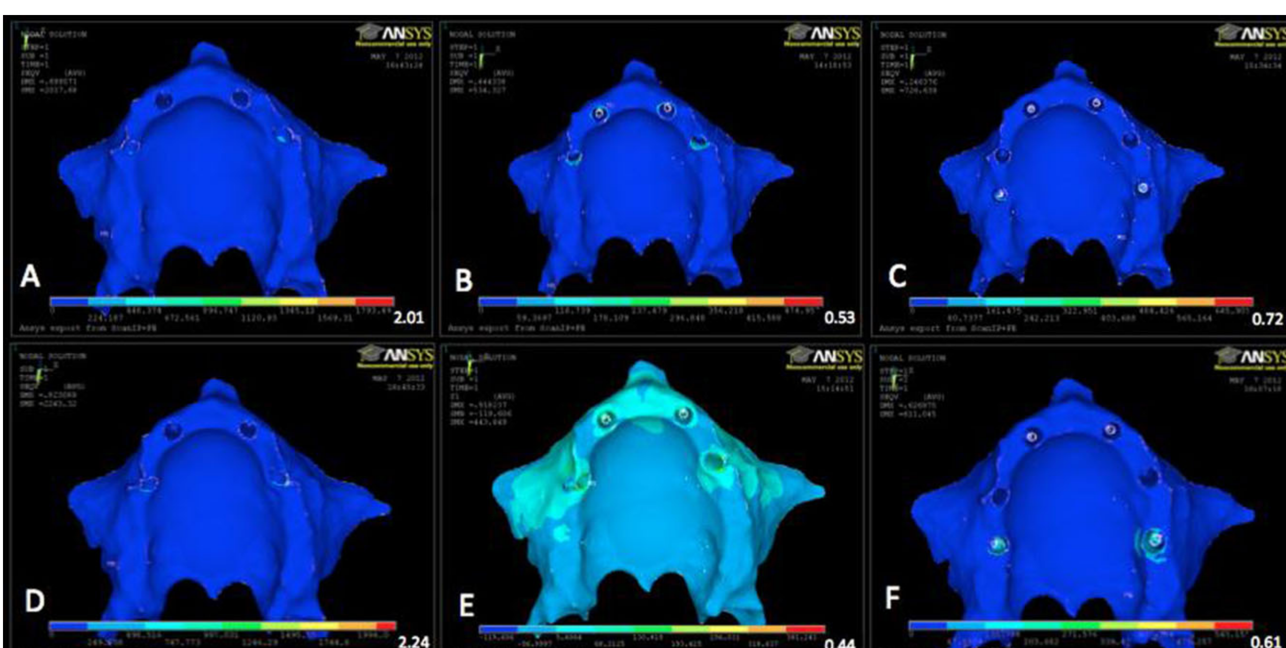

Figure 7 Von Mises stress (σvM) (GPa) in the axial (L1) and oblique (L2) loading for M4T (A and D), M4S (B and E), and M6S (C and F). The maximum values of each model were visualized around implant 1 – M4S/L1 (B), M4T/L2 (D), and M4S/L2 (E); implant 2 – M4T/L1 (A) and implant 6 – M6S/ L1 (C) and L2 (F).

implant 2 (5.5 and 7.2 GPa), and implant 3 (4.1 and 6.5 GPa). For the M4S, the highest stress value (σ_{vM}) were observed at implant number 4 (36.4 for L1 and 38.5 GPa for L2), followed by implant 1 (33.6 for L1 and 33.1 GPa for L2), implant 2 (11.2 GPa), and 3 (7.5 GPa) under axial loading and implant 3 (14.2 GPa) and 2 (12.1 GPa) under oblique loading. For M6S, the highest stress values for L1 and L2 were implant 6 (61 and 49.1 GPa), implant 1 (5.6 and 5.6 GPa), implant 4 (1.3 and 3.4 GPa), implant 3 (0.8 and 2.4 GPa), and implant 2 (0.4 and 1.6 GPa), respectively. In general, implants in closer proximity to loading area showed higher stress values, mainly under axial loading were the short implant 6 at M6S showed 99.3% higher stress than the anterior implant 2 of the same model and 19.2% higher stress in comparison to the implant 1 in the M4T. The same trends were observed under oblique loading where implant 6 presented 96.72% more stress than the implants 2 and 5 within the same model and 14.9% more stress in comparison to the implant 1 for the M4T (Table 4).

DISCUSSION

Numerical simulations are now widely used to understand the stress distributions and deformation profiles in engineering and biomedical fields. In these techniques, the accuracy of results greatly depends on the precise representation of the geometry of interest in the analyzed model. While results in initial studies relied on solid modeling tools to create approximate geometries for analysis, availability of advanced imaging techniques are now enabling accurate representation of precise 3D geometric models for FEA and other numerical analysis techniques.[46,47] The present study used a tomography of a patient to create the model of atrophic maxilla and micro-CT of the implants to simulate three different treatments modalities for fixed restoration of a total edentulous maxilla. Even though the use of fewer implants to support the prosthesis reduces the overall treatment cost[2] the reduced quantity of bone results in challenging scenarios for implant placement. Such perceived advantages may result in subsequent drawbacks due to bone and/or implant failure.[3] Thus, evaluation of the number of implants and implant angulation options commonly utilized in clinical practice are desirable prior to treatment.

The results of this study showed that the model with tilted implants (M4T) presented 32% (L1) and 48% (L2) higher σ_{max} and 73% (L1) higher σ_{vM} compared to the vertical implants (M4S) in both analysis criterium. Thus, the hypothesis, which postulated that the presence of distal tilted (*all-on-four*) implants would result in higher stress in the maxillary bone compared to vertical implants (*all-on-four*), was accepted. Concerning this topic, results contradictory to ours have been previously reported,[42] presenting decreased peri-implant bone stress when simulating tilted distal implants in a fixed denture in comparison to vertical implants with cantilevered segments.[42] Such discrepancy in results is likely related to the cantilever length reduction utilized for all tilted models relative to the vertical implant configuration in that particular study.[42] In this regard, Rubo and colleagues[48] demonstrated through 3D FEA that the increase in stress on implants is proportional to increased cantilever length, which explains the discrepancy between the previously reported results of Bevilaqua and colleagues and the present results. These findings are confirmed in the present study in relation to the implants stress values of the 14 mm right cantilever for M4T (49.4 for L1 and 41.8 GPa for L2) in comparison with the stress values in the 18 mm left cantilever (34.1 for L1 and 30.7 GPa for L2) (Figure 5A; Table 3). Based on previous findings by Bevilacqua and colleagues[42] and Rubo and colleagues,[48] along with the results observed in present study, if the distal tilted implants are to be installed splinted with vertical implants in a fixed complete prosthesis, the use of shortest cantilever for better results is suggested.

The presence of the distal short implant showed that bone in the M6S (4 vertical + 2 short implants) presented 63% (L1) and 27% (L2) higher σ_{max} in comparison to the M4S (four vertical implants; Table 3). Thus, the postulated hypothesis that the presence of the distal short implants (*all-on-six*) in association of the four vertical implants would result in lower stress in bone compared to the *all-on-four* (vertical implants) configuration was rejected. The results for σ_{max} could be explained for the positioned of the implant 6 not fully submerged in bone (Figure 2F) because of different insertion depths of the implants, resulting in a larger bending component compared to any other implant in all three models considered. It happened because the segmentation used in the present study designed the bars with the same numbers of slices for each model. So, the distance from the bar to the maxilla was maintained constant for all models as mentioned in the methodology.

Several biomechanical factors are recognized to influence the implant to bone load transfer, including bone quality in the insertion area, the nature of the bone-implant interface, the material properties of the implants and prosthesis, the surface roughness, the occlusal conditions, and the design of the implant.[49–52] In the presence of marginal bone loss, the lever arm of force will be increased, so the moment with respect to the marginal bone level will result in increased stress levels.[5–8] Specific studies using FEM described that a bone loss of 4 mm showed higher values of stress than no bone loss situation.[53]

In relation to the σ_{vM}, the implants in closer proximity to the loading area showed higher stress values compared to other. Once again, implant 6 in the M6S model presented 99.3% (axial loading) and 96.7% (oblique loading) higher σ_{vM} compared to implant 2 in the same model. Consequently, the stress at distal implants in the *all-on-four* planning would be higher than the stress in the *all-on-six* planning for this particular maxilla when model constrains had to be observed for appropriate comparison between models. It is likely that this situation over time after restoration of implant 6 in the M6S model would be questionable in a clinical scenario due to the reduced amount of bone support.[54] Nevertheless, as the stress at implant 1 to 4 were lower in comparison to the all-on-four planning, it should be considered as advantageous the presence of short implant to decrease the cantilever, even with the higher results for the implant 6.

It should be observed that there are inherent limitations in simulating clinical scenarios, primarily due to assumptions concerning forces, boundary and loading conditions, and material properties.[6,21,30,41,55,56] Bone is a complex dynamic structure and its characteristics may substantially vary among individuals, and its mechanical properties are not precisely established. In the present study, a type III bone was used to simulate the maxilla and alterations in this assumption would likely shift the numerical values of the results.[13] In addition, ideal osseointegration conditions were utilized, where 100% contact between the implant and the bone and perfect fit of implants abutments and bar were assumed in all models, which may be different than real clinical situations. However, qualitative and comparative results obtained in this study are expected to be insensitive to most of these parameters. Since the same conditions were applied to all models, these assumptions have been shown to unlikely interfere in the aims.[46]

For further investigations, the presence of prosthetic components between the implants and bar and contact pair between the implants and bone would be inserted for comparison. Additionally, different implant company and implant position would be available.

CONCLUSIONS

The hypotheses of the present study that the presence of distal tilted (*all-on-four*, *2 vertical mesial implants*, and *2 distal tilted implants*) and distal short implants (*all-on-six*, *4 anterior vertical implants*, and *2 posterior short implants*) would respectively result in higher and lower stresses in the maxillary bone in comparison to the presence of vertical implants (*all-on-four*, *4 anterior vertical implants*), were respectively accepted and rejected, as the presence of distal tilted and distal short implants resulted in higher stresses compared to vertical implants (*all-on-four*), mainly in the σ_{vM} criterium. Nevertheless, as the stresses at the majority of the implants were lower in the all-on-six planning in comparison to the all-on-four planning, it should be considered as advantageous the presence of short implant to decrease the cantilever in the σ_{max} criterium.

ACKNOWLEDGMENTS

This research was supported by the Sao Paulo Research Foundation (FAPESP # 2009/09075-8) and the Department of Biomaterial and Biomimetics of New York University College of Dentistry. The authors would like to thank the Department of Orthopedic Surgery of New York University (Dr. Peter S. Walker) and Prof. Rolf Ewers and Dr. Rudolf Seemann from the University Hospital for Cranio Maxillofacial and Oral Surgery, Medical University of Vienna for the valuable help during the course of this study.

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