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# Influência do número e inclinação dos implantes para a ancoragem de prótese fixa em maxila atrófica. Estudo comparativo com elementos finitos 3D

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**Tese apresentada à Faculdade de Odontologia do Câmpus de Araçatuba – Unesp, para a obtenção do Grau de "Doutor em Odontologia" – Área de Concentração em Prótese Dentária.**

**Orientador : Prof. Dr. Eduardo Passos Rocha**

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# RESUMO GERAL


Almeida EO. Influência do número e inclinação dos implantes para a ancoragem de prótese fixa em maxila atrófica. Estudo comparativo com elementos finitos 3D [Tese]. Araçatuba: Faculdade de Odontologia da Universidade Estadual Paulista; 2012.

**Proposição.** O objetivo deste estudo foi avaliar o comportamento biomecânico de prótese fixa implanto-suportada com implantes longos angulados e implantes curtos retos posicionados na região mais posterior de maxila moderadamente atrófica. As hipóteses foram de que a presença do implante distal longo inclinado (*all-on-four*) e do implante distal curto reto (*all-on-six*) resultariam em maior (hipótese-1) e menor (hipótese-2) tensão no osso maxilar quando comparada a presença dos implantes distais longos verticais (*all-on-four*).

**Materiais e Métodos.** O modelo 3D foi confeccionado baseado na tomografia de um paciente com maxila atrófica e na micro-tomografia dos implantes Nobel Biocare. As diferentes configurações foram: M4R, quatro implantes verticais anteriores (4X11.5 X 4X13mm); M4I, dois implantes verticais mesiais (4X11.5mm) e dois implantes inclinados distais (45°) (4X13mm); M6R, quatro implantes verticais anteriores (4X11.5 X 4X13mm) + dois implantes curtos verticais posteriores (5X7mm). Foram aplicados carregamentos bilaterais simultâneos (150N) axial (C1) e obliquo (C2) na região de cantilever posterior. Foi adotada a Tensão Principal Máxima ($\sigma_{max}$) para avaliação da

tensão óssea e a tensão Equivalente de von Mises ($\sigma_{vM}$) para avaliação dos implantes.

**Resultados.** Independente da direção do carregamento, a $\sigma_{max}$ foi maior no M4I (C1 0,87 e C2 0,85 GPa), seguido pelo M6R (C1 0,71 e C2 0,53 GPa) e M4R (C1 0,59 e C2 0,44 GPa). Os implantes mais próximos da área de carregamento apresentaram os maiores valores de tensão no planejamento M6R, seguido pelo M4I e M4R.

**Conclusões.** As hipóteses 1 e 2 foram respectivamente aceita e parcialmente negada, uma vez que a presença do implante distal longo inclinado e do implante distal curto reto resultaram em maiores valores de tensão quando comparado ao implante vertical reto. Mesmo assim, como a tensão da maioria dos implantes foi menor no planejamento com 6 implantes, a utilização do implante curto é considerada vantajosa por diminuir o cantilever.

**Palavras-chave:** análise de elemento finito, implantes dentários, osseointegração, biomecânica.

# ABSTRACT GERAL

Almeida EO. Tilted and Short Implants Supporting Fixed Prosthesis in an Atrophic Maxilla. A 3D-FEA Biomechanical Evaluation [Thesis]. Araçatuba: UNESP – São Paulo State University; 2012.

**Purpose.** This study compared the biomechanical behavior of tilted long implant and vertical short implants to support fixed prosthesis in an atrophic maxilla. The hypotheses were that the presence of distal tilted (*all-on-four*) and distal short implants (*all-on-six*) would respectively result in higher (Hypotheses 1) and lower (Hypotheses) stresses in the maxillary bone in comparison to the presence of vertical implants (*all-on-four*).

**Materials and Methods.** The maxilla model was built based on a tomographic image of the patient. Implant models were based on micro-CT 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 150N loads applied in the cantilever region in axial (L1) and oblique (45°) (L2) direction. Maximum principal stress ($\sigma_{max}$) and von Mises stress ($\sigma_{vM}$) were utilized for bone and implant stresses assessments, respectively.

**Results.** Regardless of loading direction, bone $\sigma_{max}$ was highest for the M4T (L1 0.87 and L2 0.85 GPa), followed by M6S (L1 0.71 and L2 0.53 GPa) and M4S (L1 0.59 and L2 0.44 GPa). Implants in proximity of the loading area presented highest stress values in the M6S configuration, followed by the M4T and then the M4S.

**Conclusions.** 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*), were respectively accepted and partially rejected, as the presence of distal tilted and distal short implants resulted in higher stresses compared to vertical implants (*all-on-four*). 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.

**Key Words:** finite element analysis, dental implants, osseointegration, biomechanics.

# LISTA DE FIGURAS

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# LISTA DE ABREVIATURAS

FEA = finite element analysis

Hyp = hypothesis

All-on-four = 4 implants to rehabilitate the atrophic maxilla

All-on-six = 6 implants to rehabilitate the atrophic maxilla

microCT (µCT) – microcomputed tomography

3D = three-dimensional

CAD = computer aided-design

M4S = model with 4 verticals anterior implants

M4T = model with two mesial vertical implants and two distal tilted (45°) implants in the anterior region of the maxilla

M6S = model with four vertical anterior implants and two vertical posterior implants

L1 = axial loading

L2 = oblique (45°) loading

$\sigma_{max}$ = maximum principal stress

$\sigma_{vM}$ = von Mises equivalent stress

*E* = elastic modulus

*v* = Poisson's ratio

Co-Cr = cobalt-chrome

MPa = megapascal

GPa = gigapascal

mm = milimiters

Kv = kilovolts

mAs = miliamps

kVp = kilovolt peak

µA = microampere

.STL = stereolithography

s = seconds

# = number

N = Newtons

β = beta

% = percent

Ø = diameter

º = degree

~ = approximately

e.g. = for example

i.e. = in others words

# SUMÁRIO

# 1 Introdução (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 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 towards 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 towards 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 towards 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 3D-FEA method, this study compared the biomechanical behavior of tilted long implant (*all-on-four*) and vertical short implants (*all-on-six*) to support fixed prosthesis in an atrophic maxilla. The hypotheses were the presence of distal tilted (*all-on-four*) and distal short implants (*all-on-six*) would respectively result in higher (hypothese 1) and lower (hypothese 2) stresses in the maxillary bone in comparison to the presence of vertical implants (*all-on-four*).

# 2 Materiais e Métodos (Materials and Methods)

## 2.1 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-CT of the implants (Nobel Speed ™ RP and Branemark System MkIII WP, Nobel Biocare, 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 85KV with a current of 42mAs 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 70kVp with a current of 114µA.[37] The integration time was 300, the stepping rotational angle was 0.18 degree[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, Exeter, UK) to generate the assembly of 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 towards 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 C 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 2 D – F). The *all-on-four* planning (M4S and M4T) presented a 14 mm-long distal cantilever in the right side and a 18 mm-long in the left side (Figure 2D and E), whereas the M6S presented a 2mm-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).

## 2.2 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 trabecullar type III bone.[33,39,40] The models presented linear elastic characteristics.[41] The different model components were assumed to be homogenous and isotropic.[41] No contact pair was considered. The mesh set up used pre-smoothing with 100 iterations allowing all parts change with higher quality optimisation. The volume meshing was edited manually 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, USA) for the analysis.

In Ansys 13, two load directions were bilaterally applied (150N): L1 – axial (Figure 4A and B) and L2 – oblique (45 degrees) 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 principal stress ($\sigma_{max}$) was selected as stress output for the maxilla in order to allow distinction between tensile and compressive stress.[43,44] For ductile materials such as the implants and bar, von Mises stress ($\sigma_{vM}$) output was adopted for descriptive statistical analysis.[45] The implants were numbered from 1 (left side) to 4/6 (right side) for evaluation (Figure 5A-C).

# 3 Resultados (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 ($\sigma_{max}$) was highest for the M4T (L1 0.87 and L2 0.85 GPa), followed by M6S (L1 0.71 and L2 0.53 GPa) and M4S (L1 0.59 and L2 0.44 GPa) (Table 3; Figure 6 and 7). Concerning the angular orientation of implants in the M4T (tilted) configuration, these presented 32% 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 17.2% and 17.8% higher stress in bone compared to M4S (4 implants) when the axial and oblique loadings were applied. The maximum values of each model were visualized around implant 2 (M4T), 3 (M4S) and 6 (M6S) (Figure 7 D-F, respectively).

Considering the $\sigma_{vM}$ stress in the implant components in the M4T, the highest stress value of L1 and L2 were observed at in implant number 1 (49.4 and 41.8 GPa, respectively), followed by implant 4 (34.1 and 30.7 GPa), implant 2 (5.5 and 7.2 GPa) and implant 3 (4.1 and 6.5 GPa). For the M4S, the highest stress value ($\sigma_{vM}$) 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 3).

# 4 Discussão (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 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% and 48% higher $\sigma_{max}$ compared to the vertical implants (M4S) in both axial and oblique loading conditions. 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 et al.[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 et al. and the present results. These findings are confirmed in the present study in relation to the implants stress values of the 14mm right cantilever for M4T (49.4 for L1 and 41.8 GPa for L2) in comparison with the stress values in the 18mm left cantilever (34.1 for L1 and 30.7 GPa for L2) (Figure 5 A; Table 3). Based on previous findings by Bevilaqua et al.[42] and Rubo et al.[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 17.2% and 17.8% higher $\sigma_{max}$ in comparison to the M4S (4 vertical implants) for both axial and oblique loading conditions, respectively. Although, except for implant 6, the implant stress values were lower in the M6S configuration (Imp 1 - 5.6 GPa for L1 and L2, Imp 2 – 0.4 for L1 and 1.6 GPa for L2 and Imp 3 - 0.8 for L1 and 2.4 GPa for L2) in comparison to the M4S configuration (Imp 1 – 33.6 for L1 and 33.1 GPa for L2; Imp 2 – 11.2 for L1 and 12.1 GPa for L2 and Imp 3 7.5 for L1 and 14.2 GPa for L2). Thus, the postulated hypothesis that the presence of the distal short implants (*all-on-six*) in association of the 4 vertical implants would result in lower stress in bone compared to the *all-on-four* (vertical implants) configuration was partially rejected. It should be noted that the clinical aspect of the maxilla utilized along with the need to standardize dimensions of the model for appropriate comparisons resulted in significantly reduced bone height in the posterior region of the #6 implant in the M6S model, and that particular implant was not fully submerged in bone (Figure 2F) resulting in a larger bending component compared to any other implant in all three models considered.

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 oclusal 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 $\sigma_{vM}$, 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 $\sigma_{vM}$ 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 insert for comparison. Additionally, different implant company and implant position would be available.

# 5 Conclusões (Conclusions)

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*), were respectively accepted and partially rejected, as the presence of distal tilted and distal short implants resulted in higher stresses compared to vertical implants (*all-on-four*). 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.

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# Figuras e Legendas

# Figuras e Legendas (Figures and Legends)

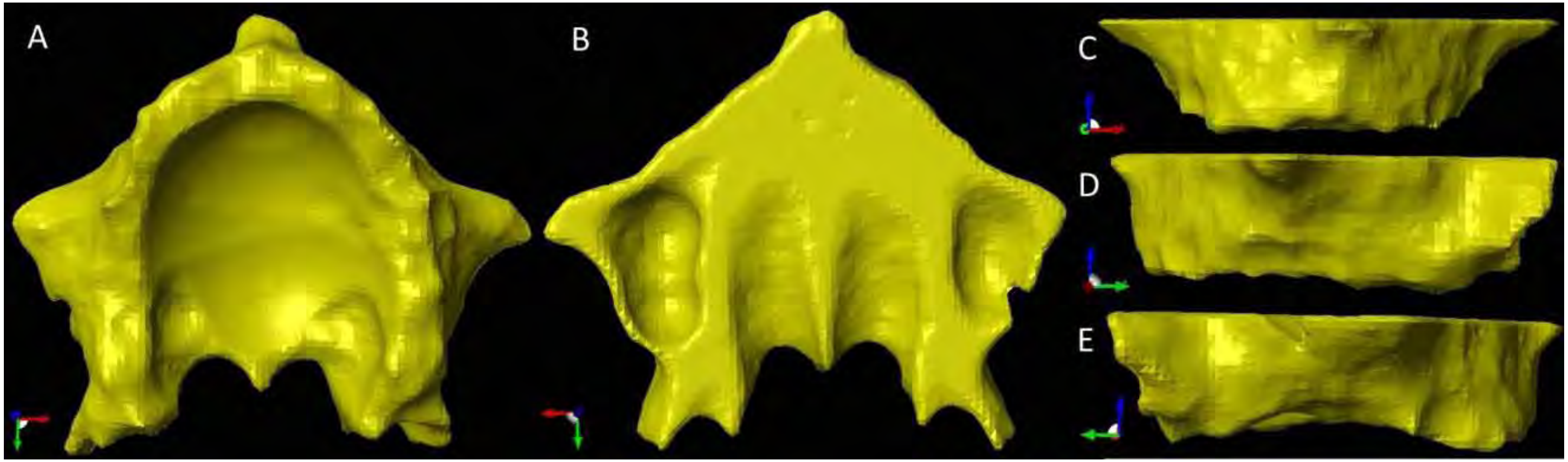


**Figure 1**: Tridimensional-CAD of the maxilla in the inferior (A), superior (B), frontal (C), lateral left (D) and lateral right (E). The red, green and blue arrows indicate the X, Y and Z direction.

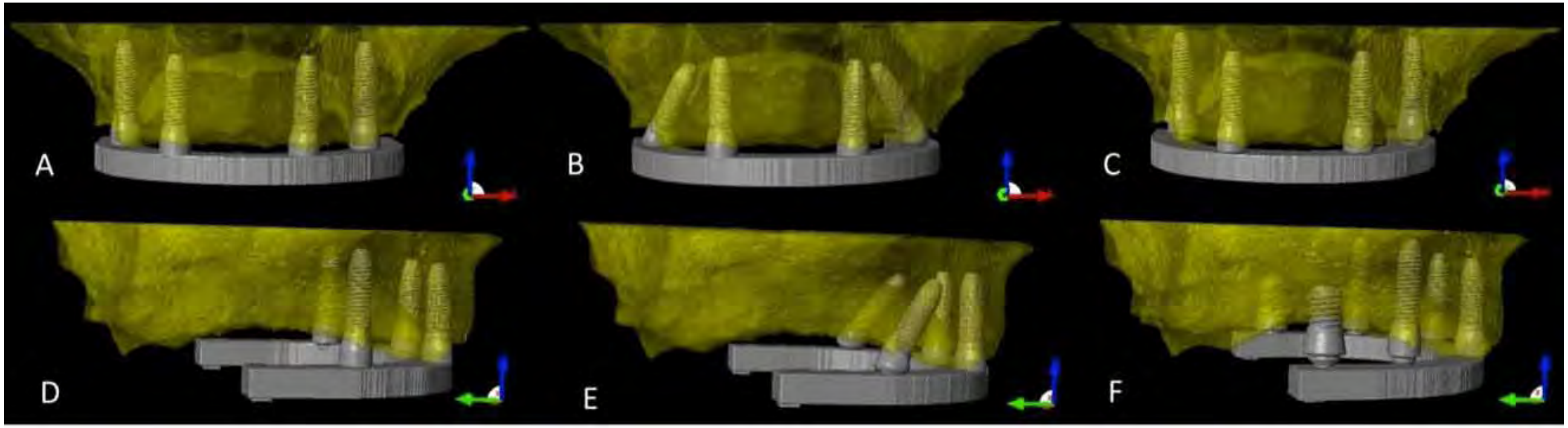


**Figure 2**: Frontal (A – C) and lateral right (D-F) view of the models M4S (A and D), M4T (B and E) and M6S (C and F). The red, green and blue arrows indicate the X, Y and Z direction.

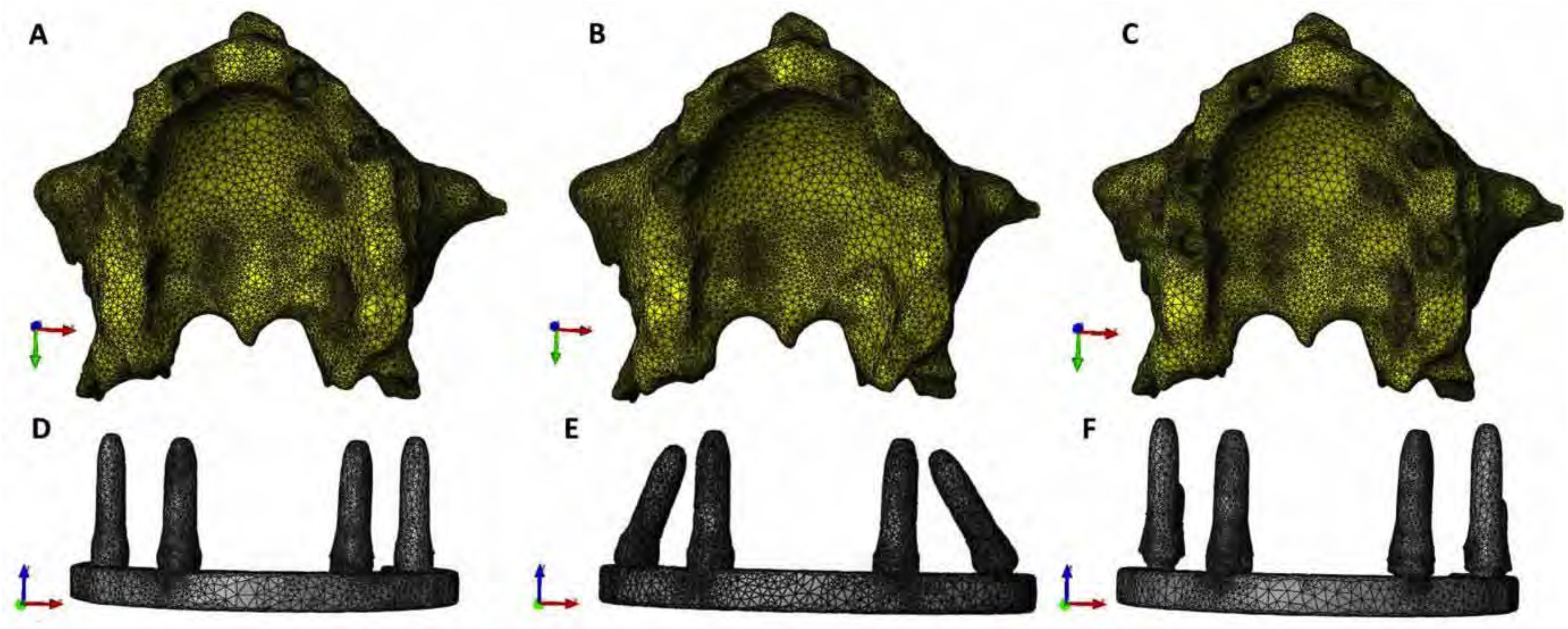


**Figure 3**: Finite element mesh of the M4S (A and D), M4T (B and E) and M6S (C and F).

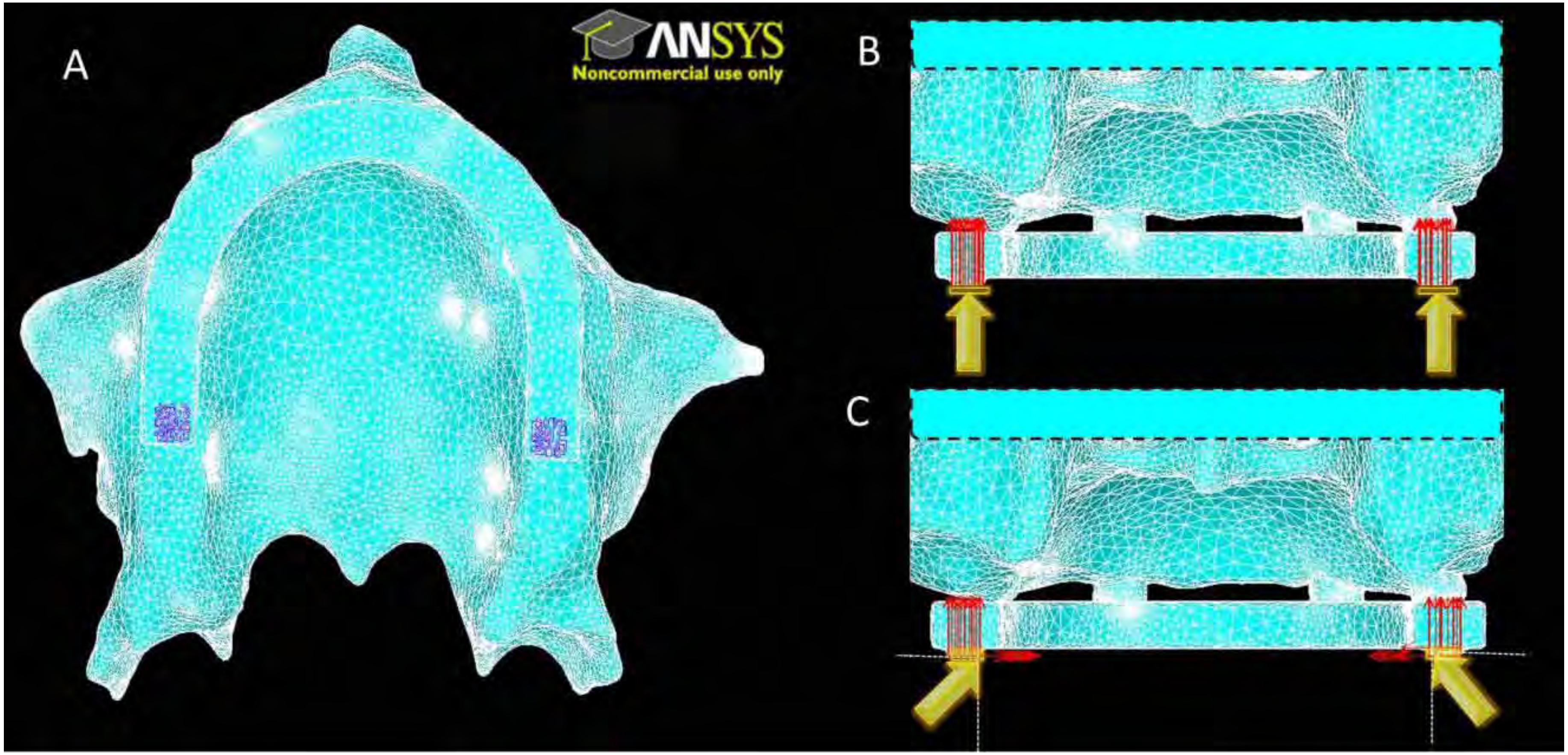


**Figure 4**: Loading area bilaterally at the bar cantilever (A). Axial - L1 (B) and oblique - L2 (C) loading in Ansys Software. Boundary condition include displacement at the top surface (identify by dotted bl) of the maxilla for axial (L1) and oblique (L2) loading (B and C).

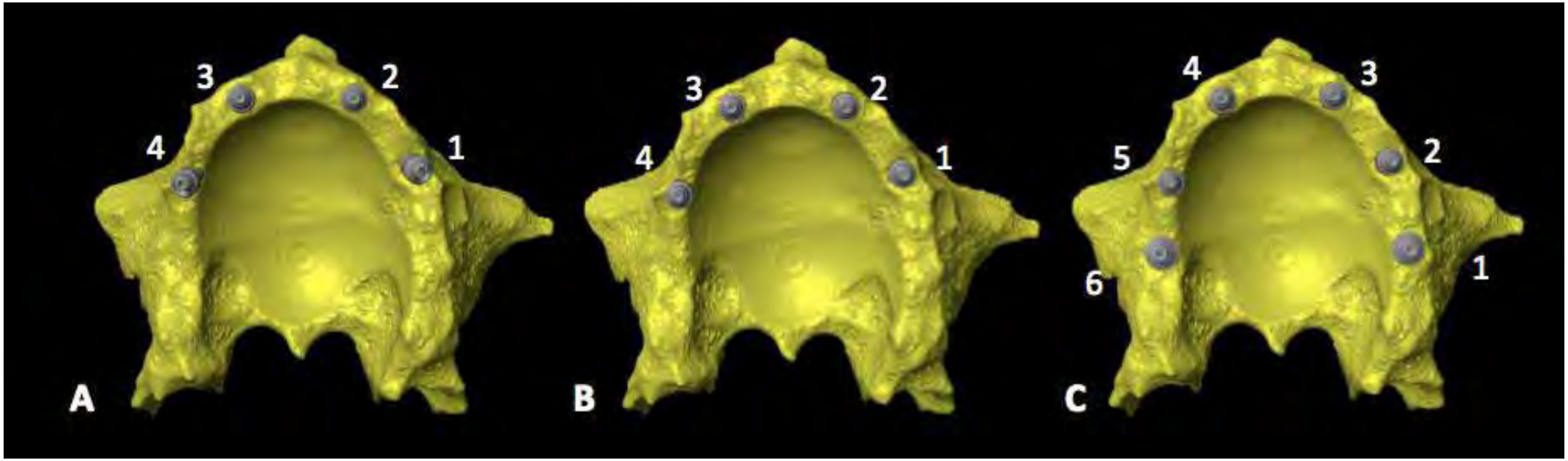


**Figure 5**: Oclusal view of the implants in the M4T (A), M4S (B) and M6S (C) planning. The numbers 1 to 4 (M4Tand M4S) and 1 to 6 (M6S) represent the implant numbers in each model for evaluation. The all-on-four configuration (M4I and M4S) shows the cantilever in the right and left side.

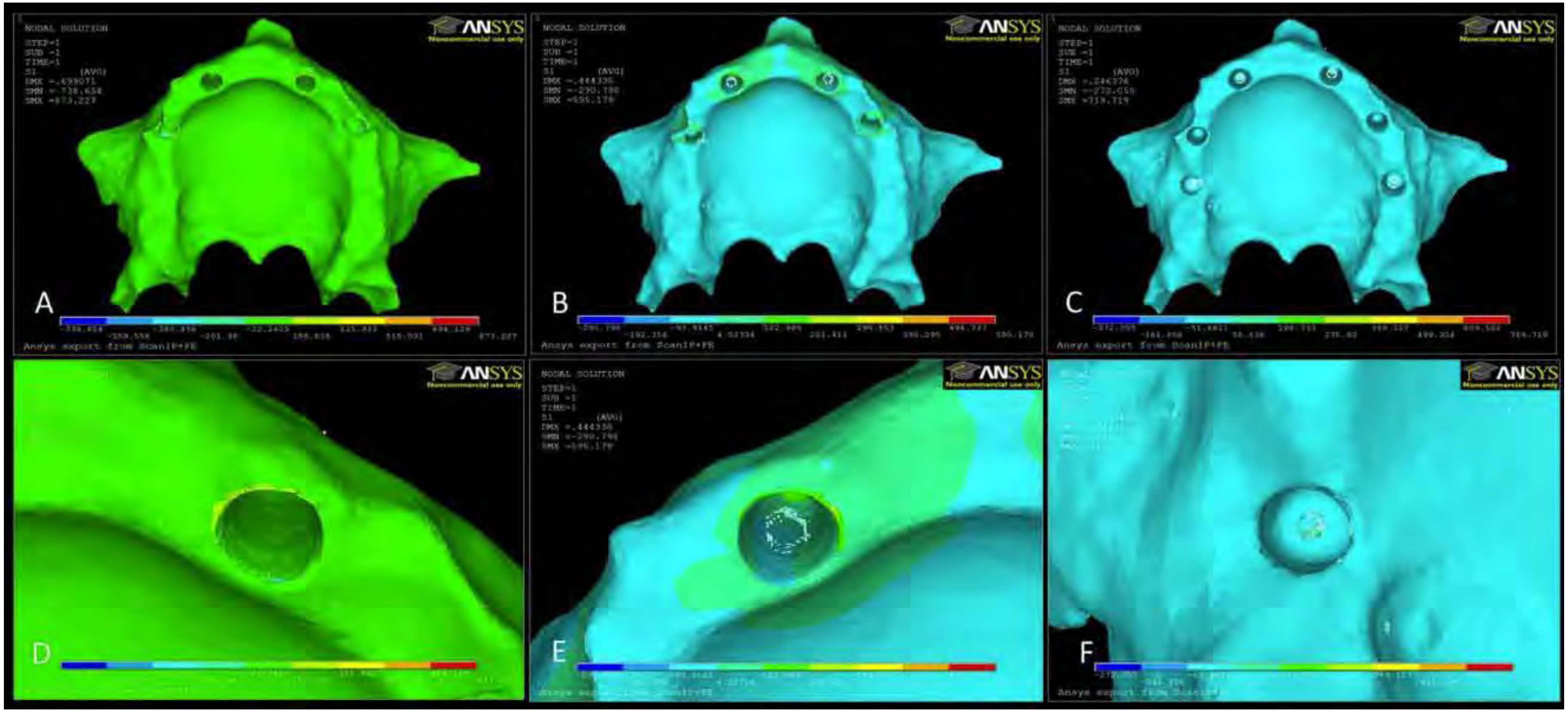


**Figure 6**: Maximum Principal Stress ($\sigma_{max}$) (GPa) in the axial loading (L1) for M4T (A and D), M4S (B and E) and M6S (C and F).

The maximum value of each model was visualized around implant 2 (M4T, Fig. D), 3 (M4S, Fig. E) and 6 (M6S, Fig. F).

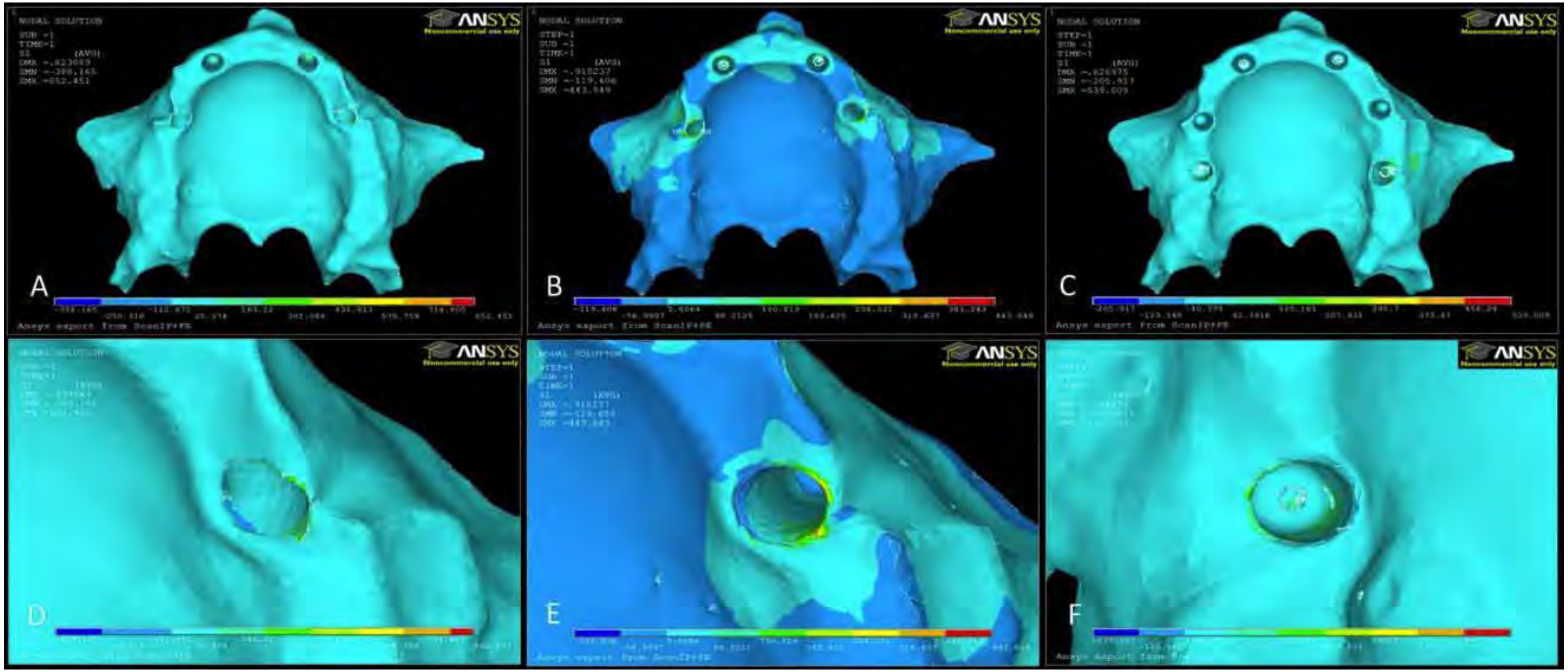


**Figure 7**: Figure 5: Maximum Principal Stress ($\sigma_{max}$) (GPa) in the oblique loading (L2) for M4T (A and D), M4S (B and E) and M6S (C and F). The maximum value of each model was visualized around implant 1 (M4T, Fig. D), 1 (M4S, Fig. E) and 6 (M6S, Fig. F).

# Tabelas

# Tabelas (Tables)

**Table 1** – Model descriptions for the present study. (Legends: M4S – model with 4 vertical implants; M4T – model with 4 implants with the tilted distal; M6S – model with 6 vertical implants; MI - mesial implants; DI - distal implants).

| Models | Implants # | Implants inclination | Region of anchorage | Implants | Multi-unit Abutments |
|---|---|---|---|---|---|
| M4S | 4 | 0º | nasal cavity<br><br>canine pillar | Nobel Speed Groovy RP 4.0 X 11.5 mm<br><br>Nobel Speed Groovy RP 4.0 X 13 mm | Straight 4.0 mm RP |
| M4T | 4 | 0º<br><br>45º | nasal cavity<br><br>canine pillar | Nobel Speed Groovy RP 4.0 X 11.5 mm<br><br>Nobel Speed Groovy RP 4.0 X 13 mm | Straight 4.0 mm RP<br><br>30º non-engaging 4.0 m RP (All-on-four) |
| M6S | 6 | 0º | nasal cavity and canine pillar<br><br>tuber | Nobel Speed Groovy RP 4.0 X 11.5 mm<br><br>Nobel Speed Groovy RP 4.0 X 13 mm<br><br>Branemark System Mk III Short WP 5.0 X 7.0 mm | Straight 4.0 mm |

**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) |
| **Trabecular bone Type III** | **1.60** | **0.30** | De Almeida et al. (2010 |
| **Titanium** | **110** | **0.35** | De Almeida et al. (2010) |

**Table 3**: Stress values (GPa) in bone, implants and bar for axial (L1) and oblique (L2) loading in the M4T, M4S and M6S models.

| MODEL | BONE $\sigma_{max}$ | IMP 1 $\sigma_{vM}$ | IMP 2 $\sigma_{vM}$ | IMP 3 $\sigma_{Vm}$ | IMP 4 $\sigma_{vM}$ | IMP 5 $\sigma_{vM}$ | IMP 6 $\sigma_{vM}$ |
|---|---|---|---|---|---|---|---|
| M4T (L1) | 0.87 | 49.4 | 5.5 | 4.1 | 34.1 | X | X |
| M4S (L1) | 0.59 | 33.6 | 11.2 | 7.5 | 36.4 | X | X |
| M6S (L1) | 0.71 | 5.6 | 0.4 | 0.8 | 1.3 | 0.5 | 61 |
| M4T (L2) | 0.85 | 41.8 | 7.2 | 6.5 | 30.7 | X | X |
| M4S (L2) | 0.44 | 33.1 | 12.1 | 14.2 | 38.5 | X | X |
| M6S (L2) | 0.53 | 5.6 | 1.6 | 2.4 | 3.4 | 1.6 | 49.1 |

# Anexo

Normas da revista ***“The International Journal of Oral & Maxillofacial Implants”*** selecionada para publicação do artigo do Capítulo 1 (Tilted and Short Implants Supporting Fixed Prosthesis in an Atrophic Maxilla. A 3D-FEA Biomechanical Evaluation).

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1. Johansson C, Albrektsson T. Integration of screw implants in the rabbit: A 1-year follow-up of removal torque of titanium implants. Int J Oral Maxillofac Implants 1987;2:69-75.

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1. Skalak R. Aspects of biomechanical considerations. In: Brånemark P-l, Zarb GA, Albrektsson T (eds). Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985:117-128.

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