TITLE

INFLUENCE OF THE BONE QUALITY IN THE MECHANIC INTERACTION BETWEEN IMPLANT AND BONE: A FINITE ELEMENT METHOD STUDY

Keywords: Dental implants, Bone quality, Finite Elements.

ABSTRACT

Objectives

The aim of this study is to evaluate, by using numerical simulation techniques based on the finite element method, the influence of the different types of bone in reference to their different bone densities and cortical zone thicknesses, in the stresses induced by two implants in occlusive and oblique loads.

Methods

Two different types of implants were used: Acqua M-12 and Astra Tech. These implants were introduced in a model or matrix whose geometry was extracted from a real CBCT radiograph of the posterior mandibular area. Young's modulus and Poisson's coefficient corresponding to the different bone qualities described by Misch were given. Different loads were applied with an amplitude equal to 400 N with different directions: occlusive and oblique 15° to 5mm above the uppermost part of the implant.

Results

The Von Mises variant was analyzed. In occlusive load, both implants present a greater tension in the area of cortical bone than in the area of trabecular bone, as a consequence of the greater rigidity of cortical bone compared to trabecular bone. For the condition of oblique load, it can be seen that in both implants the stresses obtained in the cortical zone increase significantly with respect to those obtained for occlusive loads.

Conclusions

Good mechanical behavior for both occlusive and oblique loads was seen. The decrease in bone quality negatively affects the stresses produced by the implant, mainly in the area of cortical bone. The AQUA implant presents lower tensions in the cortical bone area than the ASTRA implant for the four types of bone. In contrast, the tensions obtained in the area of trabecular bone are greater for bone types III and IV in the AQUA implant than in the ASTRA implant.

INTRODUCTION

The use of implants to replace dental losses has become a common practice in the daily practice of the dentist. Different types of implants have been designed, tested and presented in the market in order to provide prosthetic, anatomical, aesthetic and functional solutions in patients with partial or total loss of their teeth. Currently there are multiple implant systems in the market and its reliability is supported in different clinical studies

Despite the high success rate of dental implants, there are several factors that lead to complications and subsequent failure of treatment. Clinically, some of the main causes of failure in implantology are incomplete osseointegration, complications with the surrounding soft tissues, biomechanical problems (1) and parafunctional habits, where bruxism should be highlighted, causing rejection of the implant due to bone loss in the interaction zone

The aim of this study is to evaluate, by using numerical simulation techniques based on the finite element method, the influence of the different types of bone in reference to their different bone densities and cortical zone thicknesses according to Misch´s Classification(2), in the stresses induced by two implants in occlusive and oblique loads.

MATERIAL AND METHOD

1. Dental implants

Two implants with a diameter of 4 mm and a length of 13 mm were used, with the following characteristics:

• M-12 (AQUACM4013-Oxtein-Italy): Tapered implant with double internal hexagon, grade IV titanium and surface treated with Argon. It has coronal micro-threads, double U-spins in the middle third and micro-threads in the valleys, which increases the contact surface with the bone. (Figure 1)

• ASTRA TECH 4013 (Dentsply Sirona-USA): Straight implant with double internal hexagon, grade IV titanium, surface blasted with titanium dioxide and modified with fluorine (Figure 2).

The mechanical properties of the implants used in the numerical models are:
• Young's module = 110 GPa
• Poisson Coefficient = 0.3

2. Types of bone

Following the bone density scheme according to Misch (2), there are four types of bone in the jaws depending on the density and thickness of the area with cortical bone.

For the comparative study between the AQUA and ASTRA implants, the influence of the four bone types defined in Table 1 was studied, with densities and cortical zone thicknesses defined in Table 2.
The basic geometry of the bone has been extracted from a real radiography of the posterior mandibular area, defining from it the dimensions of the bone to be modeled. The depth has been set at 10 mm and to properly house the implant, the upper area has been cut to leave a free surface 6.5 mm wide

3. Applied loads
The implants have been analyzed for two different loading conditions with amplitude equal to 400 N, (2,3):

- Occlusive load.
- Oblique load with an angle of inclination of 15° (Figure 3).

4. Finite elements model.

All the analysis have been carried out by applying the Finite Element Method through the use of commercial software Abaqus Standard 6.14.2. The meshing of the two materials has been done using C3D4 elements, first order tetrahedra, with an average mesh size of 0.05 mm. At the same time, embedment contour conditions have been imposed on the base and the Y movement has been restricted in the lateral sections of the tooth. (Figure 4)

The perfect adhesion between bone and implant has been modeled considering that the finite elements of bone and implant in the interaction surface share nodes.
The point of application of the loads has been placed at 5 mm with respect to the upper surface of the cortical bone and it has been distributed through the use of a rigid interpolation element in order to impose restrictions between the degrees of freedom of a set of nodes and the movement of a rigid body, defined by a reference node.

The constitutive model used to characterize the implant and the bone has been linear isotropic elastic (4), with Young's modules for the bone defined according to the density of the type of bone under study (2) (Table 2).

RESULTS

After the analysis of the four bone configurations for the two proposed load conditions, maximum stress values were obtained both in the cortical bone zone and in the trabecular bone area.

The Von Mises variant has been taken as the evaluation value of tension. Although the von Mises criteria is defined mainly to define the behavior in ductile materials, its use is adequate in the tensional analysis of the bone for loads in elastic regime.
The tensions obtained in the area of trabecular bone are simulated tensions, not taking into account the percentage of porosity or dimension of the cavities that make up the type of bone analyzed.

OCCLUSIVE LOAD

Both implants present a greater tension in the area of cortical bone than in the area of trabecular bone, as a consequence of the greater rigidity of cortical bone compared to trabecular bone (Figure 5 and Figure 6). The effect increases as the quality of the bone decreases, and consequently the difference in stiffness between cortical and trabecular zones increases.

The AQUA implant presents less mechanical support in the area of cortical bone than the ASTRA implant. This effect translates into lower tensions in the cortical zone and, in contrast, higher in the area of trabecular bone (Figure 7 to Figure 9). This effect increases as the quality of the bone decreases.

Dental prostheses have similar tensions in the trabecular bone area for type D1 and D2 bones. However, for those of type D3 and D4, a greater increase in stress is observed in the AQUA implant than in the ASTRA. This is because the teeth of the thread of the ASTRA implant bear a greater load due to its larger size that induces a stress concentration more accentuated at the base of the tooth of the thread (see Figure 10 bone type D3 and D4).

OBLICUE LOAD - 15º

It is observed that in both implants the stresses obtained in the cortical zone increase significantly with respect to those obtained for occlusive loads, being 200% higher for the AQUA implant and 275% higher for the ASTRA implant. for the type of bone D4. This behavior is derived from the effects of bending and shear produced by the lateral component of the load in the first zone of support of the implant on the bone, which together with the high rigidity of this cortical zone with respect to the area of trabecular bone, leads to much higher stresses.

The previous phenomenon also affects the area of trabecular bone, although with a lower impact, with increases for bone type D4, 33% for the AQUA implant and 28% for the ASTRA implant.

For the performance of the two implants studied, the trend is similar to that obtained for occlusive loads (Figure 11 and Figure 12), with a better behavior of the AQUA implant in the cortical zone, and higher tensions in the trabecular bone area, mainly for bones of type D3 and D4.

The cause of the greater stresses of the AQUA implant in the area of trabecular bone come from the same cause defined for the occlusive load condition, derived from a greater dimension of the teeth of the threads of the dental prosthesis in the apical area, which induces higher concentrations of tensions at the base of the tooth of said thread (Figure 16 bone type D3 and D4).

DISCUSSION

In this study, the mechanical behavior of two commercial dental implants subjected to a maximum mastication force equal to 400 N (2,3) was presented for different types of bone quality according to the bone density classification defined by Misch(2).

Las Casas et cols.(5) in 2008 did not find any differences between two wedge-shaped implants designs. They did not make any difference in the FEM between cortical and trabecular bone.

The behavior of the bone and its interaction with the implant for both occlusive and oblique loads with a maximum angle of inclination of 15° has been studied, evaluating the tensions in both the cortical and trabecular bone area.
Numerical modeling has been carried out considering bone materials as linear isotropic (4).This idealization is of direct application to the cortical bone, due to its low porosity and the elastic behavior of the bone at the macroscopic level for the evaluated load state. The application of this constitutive model of material for trabecular bone is conditioned by the definition of an apparent Young's module that adequately represents the macroscopic behavior of the trabecular bone, taking into account the percentage of porosity and the dimensions of the cavities that make up bone. Consequently, the tensions obtained in the trabecular bone are also apparent tensions, which do not take into account the stress concentrations derived from the percentage of porosity and the dimensions of the trabecular bone cavities, which are lower than the actual stresses existing in the trabeculae of the bone.
The evaluation of the BIC for type D4 bone qualitiy has been presented informatively, due to the actual specific stresses are above the resistance capacity of the bone, causing the trabecular bone to break.

From the study of the results curves for occlusive load (Figure 5 and Figure 6) and for oblique load (Figure 11 and Figure 12), there is a direct relationship between the increase in stresses in the cortical bone as the quality of the bone decreases. This effect can not extend to the area of trabecular bone, because the ASTRA implant does not present significant tension increases in the trabecular bone area and the AQUA implant is only affected for the bone qualities type D3 and D4 being increasement derived very possibly from the thread design in the trabecular zone.

Geramizadeh et cols.(1) In 2018 compared three different implants according to their macrogeometry by using a FEM model. They concluded that a tapered implant with micro-threads in the upper area and V-shaped threads in the rest of the body has the most uniform and desirable stress distribution in the surrounding cortical bone

Our research was performed with a bone-implant contact (BIC) rate of 100%. Some autors estimate that the real BIC is between 40-70%(6,7). There is one techniques called ultraviolet functionalization of titatium on intregration with bone that allows up to 98% of BIC(8,9) being osseointegration faster(10). This higher BIC can lead to reduce the periimplant stress (11) improving distribution and diffusion of periimplant stress more effectively than using longer implants.

The design of the implant is a key factor in the primary stability of the implant and in the distribution of the stress. In some situation like when D4 bone quality is present or osteoporotic bone, the expandable implant and neck tapered implant show better stress distribution and, when it comes to stability, tapered implants shows better results(12). Longer screw-type implants could be a better choice in a jaw with cancellous bone of low density(13)

Finally, it should be noted that areas of higher stress concentration are susceptible to loss of bone material, increasing the probability of failure of the implant (1), especially those obtained in the cortical area, due to the greater rigidity of this area compared to the zone of trabecular bone and consequently to the greater participation in the stability of the implant.

CONCLUSIONS

Based on the study that has been carried out, the final balance of the investigation is as follows:

- Both implants studied have a good mechanical behavior for both occlusive and oblique loads, with distributions of tensions compatible with the resistance of the maxillary bone and similar mean tension stimuli.
- The decrease in bone quality negatively affects the stresses produced by the implant, mainly in the area of cortical bone.
- The AQUA implant presents lower tensions in the cortical bone area than the ASTRA implant for the four types of bone. In contrast, the tensions obtained in the area of trabecular bone are greater for bone types III and IV in the AQUA implant than in the ASTRA implant.
- Given the magnitude of the maximum stresses obtained in the area of cortical bone, both implants can cause loss of bone material under cyclic mechanical loads, this loss being more pronounced in the ASTRA implant due to the higher maximum stresses obtained.
- The higher tensions obtained in the area of trabecular bone for the AQUA implant for bone types III and IV are a consequence of the thread design defined for that area, where a larger tooth size allows a greater load transfer that results in concentration of tensions at the base of the tooth of the thread.

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TABLES

Table 1. Misch´s bone density classification (2)

Bone Density	Description	Anatomical Location
D1	Dense Corticae	Mandibular Anterior Zone
D2	Porous Corticae and thick trabecular	Mandibular Anterior Zone Mandibular Posterior Zone Maxilla Anterior Zone
D3	Porous Corticae and thin trabecular	Maxilla Anterior Zone Maxilla Posterior Zone Mandibular Posterior Zone
D4	Thin trabecular	Maxilla Posterior Zone

Table 2. Mechanic and geometric properties depending on the type of bone

	Corticae Bone			Trabecular Bone	
Type of Bone	Thickness (mm)	Young's module (GPa)	Poisson Coefficient	Young's module (GPa)*	Poisson Coefficient
D1	2.5	13.7	0.3	9.5	0.3
D2	2.0	13.7	0.3	5.5	0.3
D3	1.5	13.7	0.3	1.6	0.3
D4	1.0	13.7	0.3	0.69	0.3

* Simulated Young´s module.

FIGURES

Figure 1. General View of the model for AQUA M12 Implant

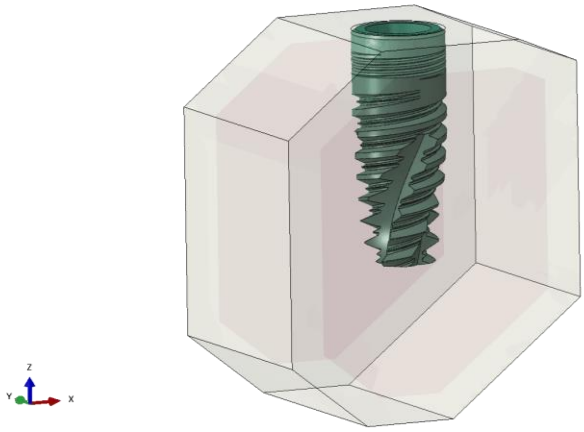


Figure 2. General View of the model for Astra Tech Implant

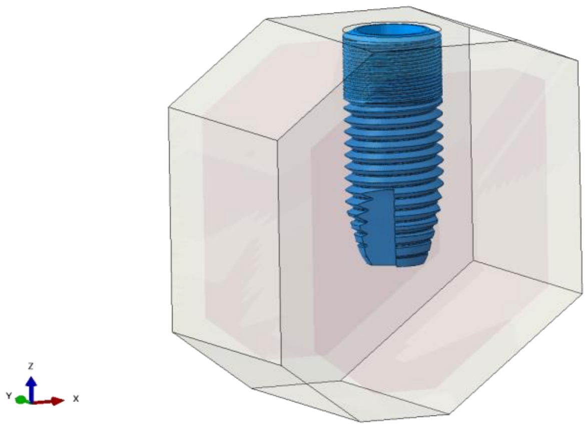


Figure 3. Types of loads analyzed

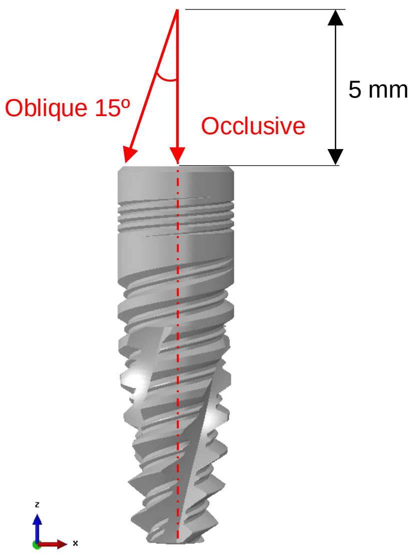


Figure 4: Contour conditions and load status for the AQUA implant model

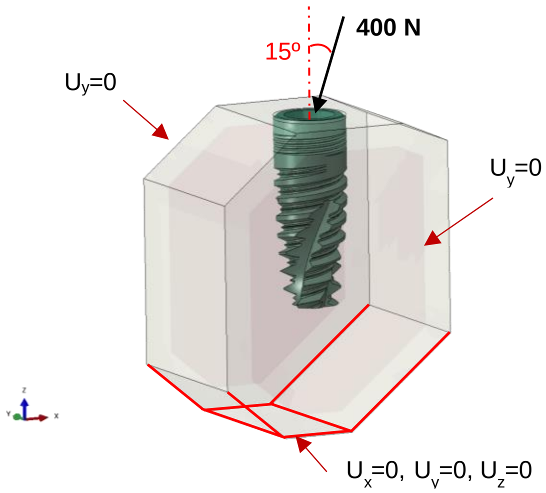
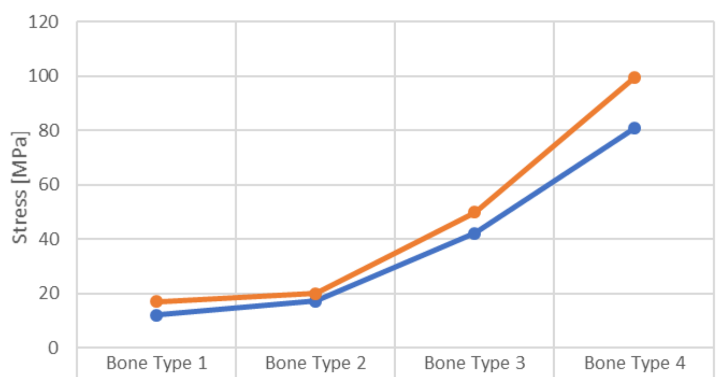


Figure 5: Maximum tension in the area of cortical bone according to bone type for occlusive load



	Bone Type 1	Bone Type 2	Bone Type 3	Bone Type 4
AQUACM4013	12	17.1	42.1	80.8
ASTRATECH4013	17	19.9	49.9	99.3

Figure 6: Maximum tension in trabecular bone area according to bone type for occlusive load

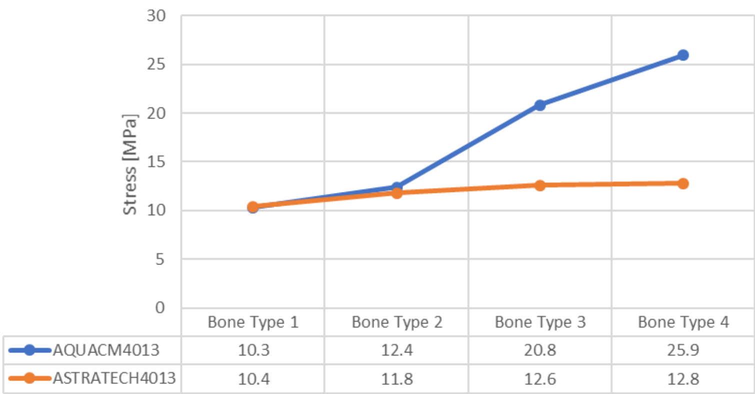


Figure 7: Tension state (Von Mises) for the ASTRA implant under occlusive load. [MPa]

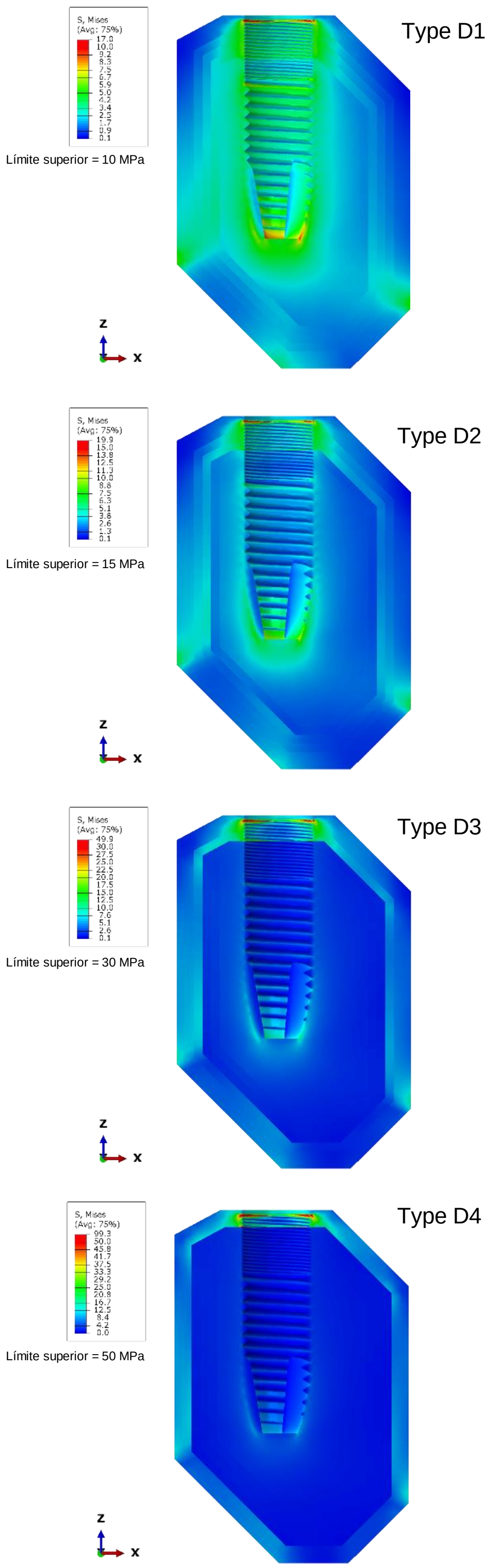


Figure 8: Tension state (Von Mises) for the AQUA implant under occlusive load. [MPa]

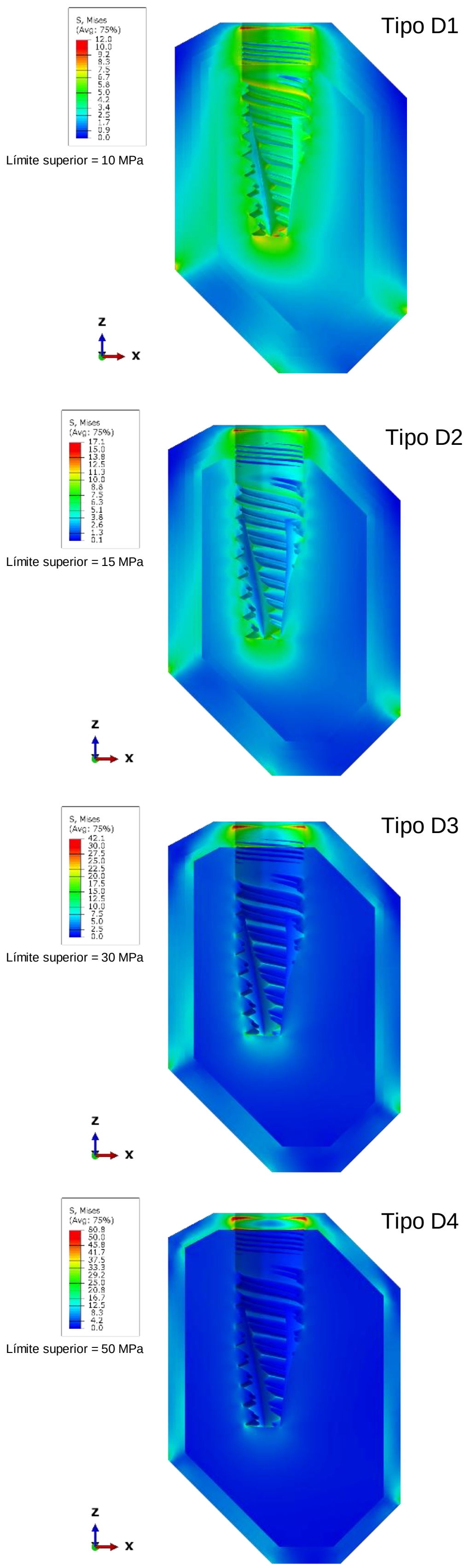


Figure 9: Tension state (Von Mises) for the ASTRA implant under occlusive load. Trabecular bone area. [MPa]

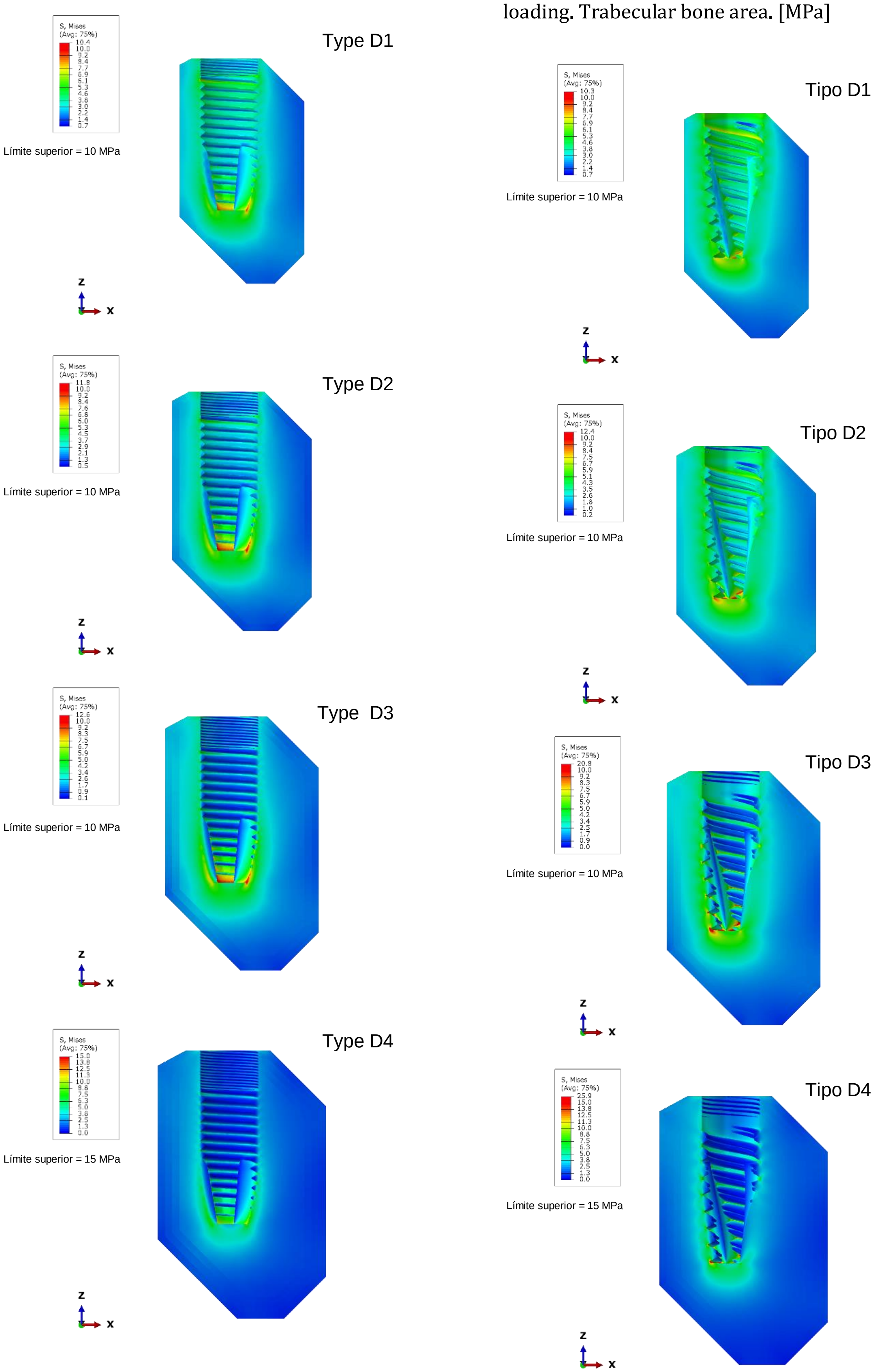
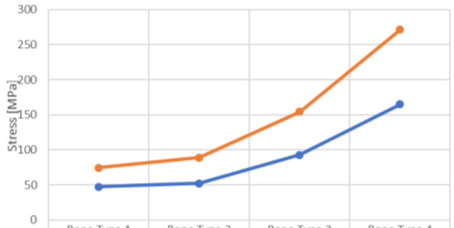


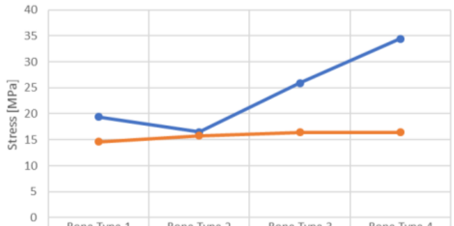
Figure 10: Tension state (Von Mises) for the AQUA implant under occlusive loading. Trabecular bone area. [MPa]

Figure 11: Maximum tension in cortical zone according to bone type for oblique load (15º)



	Bone Type 1	Bone Type 2	Bone Type 3	Bone Type 4
AQUACM4013	47.3	52.3	92.9	165.1
ASTRATECH4013	74.4	89.1	154.5	271.6

Figure 12: Maximum tension in trabecular bone area according to bone type for oblique load (15º)



	Bone Type 1	Bone Type 2	Bone Type 3	Bone Type 4
AQUACM4013	19.4	16.5	25.9	34.4
ASTRATECH4013	14.6	15.8	16.4	16.4

Figure 13: Tension state (Von Mises) for the ASTRA implant under an oblique load

(15º). [MPa]

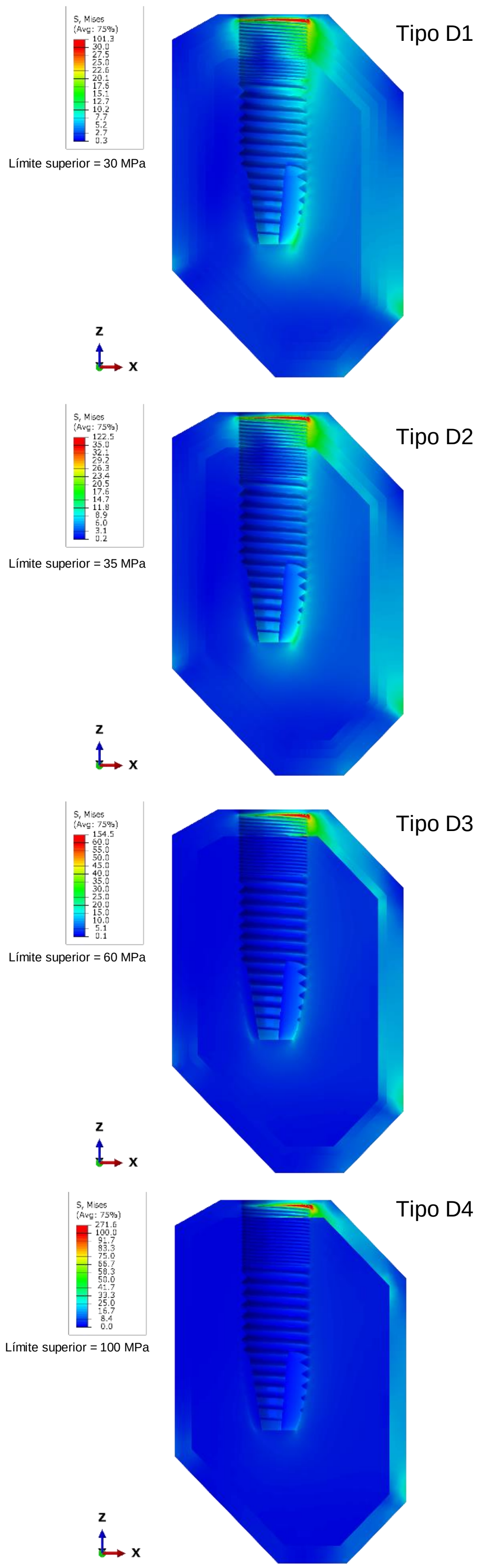


Figure 14: Tension state (Von Mises) for the AQUA implant under an oblique load

(15º). [MPa]

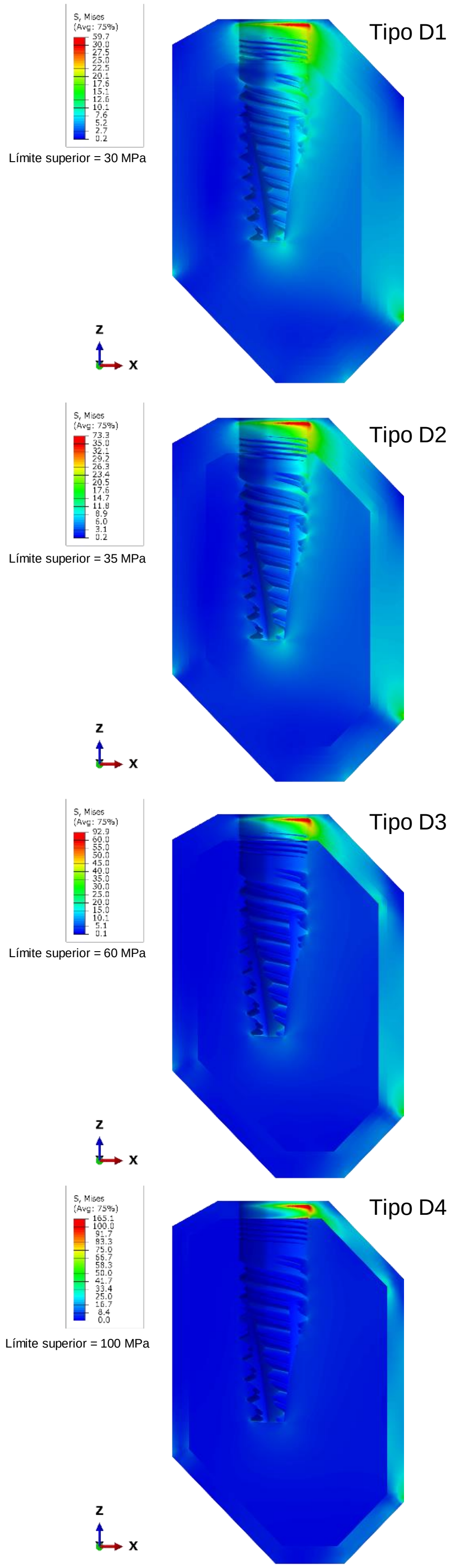
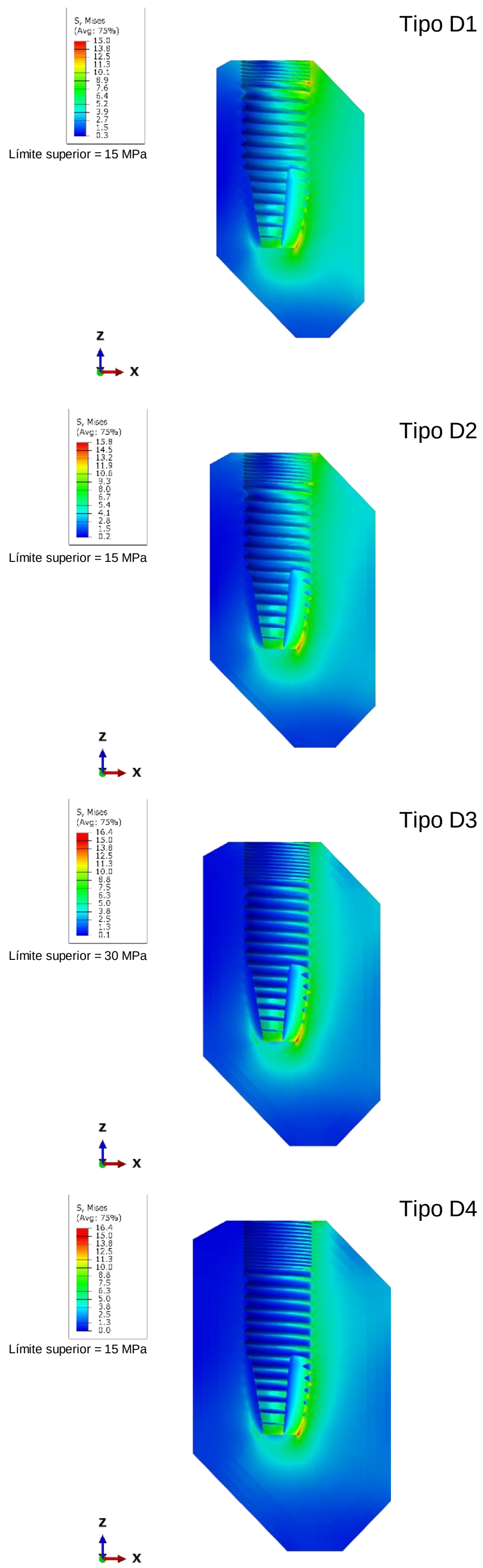


Figure 15: Tension state (Von Mises) for the ASTRA implant under occlusal load.

Trabecular bone area. [MPa]

loading. Trabecular bone area. [MPa]



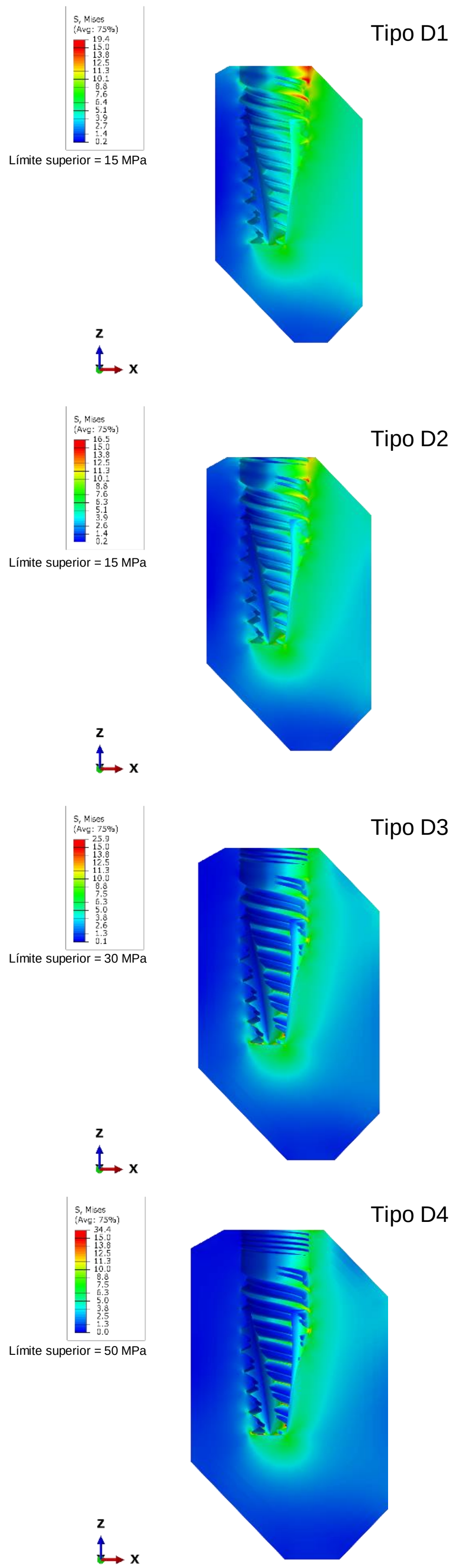


Figure 16: Tension state (Von Mises) for the AQUA implant under occlusive