Effect of force angle on the strain distribution of osseointegrated dental implants

L Forero, R. Castilla, Octavio Andrés González Estrada

Journal of Physics: Conference Series

Effect of force angle on the strain distribution of osseointegrated dental implants

Effect of force angle on the strain distribution of osseointegrated dental implants

L Forero[1], **R Castilla**[1] **and O A González-Estrada**[1]
[1] Grupo de Investigación en Energía y Medio Ambiente, Universidad Industrial de Santander, Bucaramanga, Colombia

E-mail: agonzale@uis.edu.co

Abstract. In this work, we investigate the response of the anisotropic maxilla bone in the peri-implant region, when osseointegrated implants are subjected to external forces at different angles, based on the stress and strain distribution by the finite element method. Models were created to represent a portion of a maxilla bone (upper first molar region) with two types of implants which have different thread geometry (squared and V-shaped) and material (Ti-6AL-4V ELI and grade IV Titanium). Compressive axial (150 N) and oblique load (150 N at 45° angle) were applied to anisotropic models of the bone tissues. Complete osseointegration was assumed. Results demonstrated that the increase of the implant inclination leads to a more critical behaviour. Oblique loading is more detrimental to stress and strain distribution than axial load. Stress fields were more efficiently distributed by squared thread implants.

1. Introduction

In the particular phenomenon of edentulism [1], periodontal diseases, traumatisms, orthodontic complications, endodontic failures, dental caries or tooth decay, can lead to the partial or complete loss of teeth, which carries health and emotional problems, affecting directly the quality of life of a person. Dental implants inserted into the maxilla or mandible bone are a common alternative for teeth replacement, with an efficacy rate of 94% [2]. The osseointegration of dental implants offers plenty of benefits to the patient compared with removable prostheses dentures, it gives greater support to the denture [3], and improves the aesthetics, but making the decision of using dental implants must be taken under a careful analysis of the biological conditions of the patient, due to complications that may occur which can carry to a worse circumstance. Some of the criteria the dentists should study in order to choose the right treatment are the state of the lip support, related to the undesired resorption of the alveolar bone, facial profile, smile line and amplitude, upper lip length, intermaxillary relationship, bone density and soft tissue thickness [4].

The research on the design of dental implants has allowed the high rates of effectiveness in the osseointegration processes, however, there are still complications due to factors such as the location of the implant, the surgical procedure and bone composition [5, 6], generating overloads which lead to loss of bone tissues [7] and implant failure. Moreover, the presence of axial and oblique loads affects the distribution of stress concentration based on the angle of the implant. As Pellizer, *et al.* [8] concluded, independently of the crown type, the condition of a higher angulation is directly related to a higher stress value.

The finite element analysis (FEA) has been widely used for damage evaluation [9], material characterisation [10], and biomechanical applications [11] for many years. It has been used for implant dentistry since the '70s to predict biomechanical performances on the implant-bone interface [12], providing a tool to consider the large number of variations within patients [6,13].

In this work, we compare the response of the anisotropic maxilla bone, in the peri-implant region, when osseointegrated implants are placed and forces are applied at different angles. We perform FEA for two types of implants locally distributed. By using the results of this study, professionals can address it to understand the consequences of the forces applied to osseointegrated implants.

2. Materials and methods

The failure rate of implants in the maxilla is higher than in the jawbone [14]. Thus, the analysis was performed in the maxilla to reproduce a critical condition. We assume a complete osseointegration between implants and natural tissues. The portion of maxilla bone selected from the computed axial tomography (CAT) of the patient was modelled as an anisotropic material, based on the density provided by the data of the CAT scan, to approximate to real conditions.

2.1. Segmentation of the bone

We considered the case of a female patient around fifty years old, who suffered a fracture in an upper first molar and went under surgery to remove the tooth [6]. With the help of the practitioner, the bone was classified as Type II in the Lekholm and Zarb [15] classification. Type II bone based on Hounsfield scale is when a thick layer of compact bone is surrounding a dense trabecular bone core (750-1250 HU) [16]. We segmented the region of the upper first molar with the software Materialise Mimics v19.

2.2. Dental implants

For this study, we selected two implants: TLX3409 from BioHorizons [17] and KDA0F3602 from GMI-Ilerimplants Group [18]. The TLX3409 is a mount-free tapered internal implant made of titanium alloy (Ti-6AL-4V ELI). The KDA0F3602 is machined in CP grade IV Titanium. Table 1 shows the material properties and Figure 1 shows the geometry for both models [6]. The TLX3409 has a square thread that yields higher functional surface for higher bone-implant contact. The KDA0F3602 has a V-shape thread design. The recommended dimensions of the implant for the patient are 3.5 mm diameter and 9.5 mm in length. Thus, for the two implant references, we have 3.4 mm diameter and 9.0 mm in length for the TLX3409, and 3.3 mm diameter and 10.0 mm in length for the KDA0F3602.

Table 1. Material properties of the dental implants.

Brand	Reference	Material	Modulus of elasticity (GPa)	Poisson's ratio
BioHorizons	TLX3409	Ti-6AL-4V ELI	120	0.31
GMI	KDA0F3602	CP grade IV Titanium	110	0.35

(a) (b)

Figure 1. Isometric and lateral view of the (a) TLX3409 and (b) KDA0F3602 three-dimensional solid models.

2.3. Load application

The implants support occlusal forces during its functional phase, the axial force represents the normal chewing ability which is the masticatory force, while the oblique force represents a special masticatory force, due to eating irregular food [19]. Table 2 displays the values of axial and oblique loads employed in different studies, the data shows that the most used values are in the range between 50 N and 150 N for the axial load, and 100 N to 150 N for the oblique load. Considering the previous information, in this study the axial load applied is 150 N and the oblique load is at a 45° angle w.r.t. the implant axis with a magnitude of 150 N.

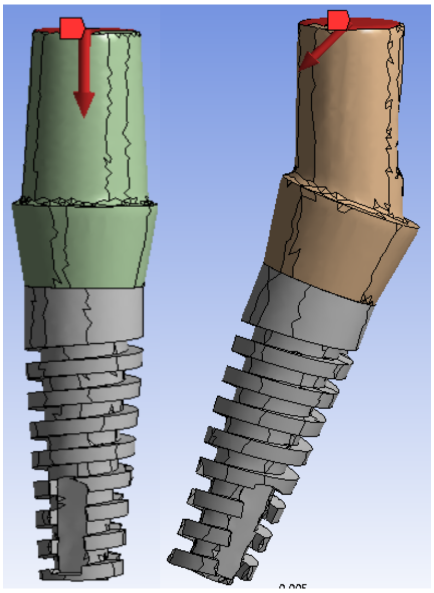

Figure 2. Example of two models indicating the directions of the forces applied to the implants.

Figure 2 shows the forces applied to the abutments of the implants, which have the same material properties as them, notice that the oblique load is applied in the direction of the implant inclination. As boundary conditions, fixed supports were applied to the lateral faces of the models which are restricted by the rest of the maxilla.

Table 2. Load values applied in previous FEM studies for dental implants.

Authors	Axial load (N)	Oblique load (45°) (N)
Anitua, *et al.* [20]	114	-
Cheng, *et al.* [19]	500	500
Chica, *et al.* [13]	-	1
Geng, *et al.* [21]	-	141
Macedo, *et al.* [22]	150	150
Minatel, *et al.* [23]	50	-
Pellizer, *et al.* [8]	100	100

2.4. Finite element models

Most dental implants studies with FEM are developed under isotropic and ideal conditions, which may not relate to real cases because the bone composition is almost unique for each patient. Two types of models are considered as in [6], see Figure 3. Type 1: Anisotropic with cylinder of cortical bone. Type 2: Anisotropic bone. The anisotropic models have 10 different materials, its distribution and Young's modulus values are given by the density obtained from the CAT scan, in a range between 500 MPa and 15000 MPa, based on the Hounsfield scale [6,24].

The meshing of the models was done in the 3 Matic software, using linear tetrahedrons with 8 nodes (SOLID185). After mesh independence verification, we selected a mesh of elements with a characteristic length of 0.3 mm.

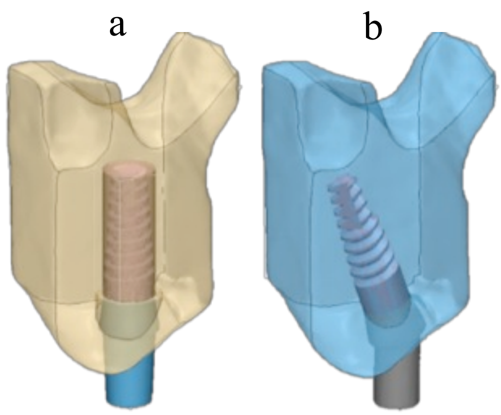

Figure 3. FE models developed: (a) Type 1, anisotropic model taken from the CAT SCAN with cortical bone allograft, (b) Type 2, anisotropic model taken from the CAT SCAN without allografts.

3. Results

We evaluate the stress and strain fields under axial and oblique loads. The physiologic maximum strain is 4000 microstrain [24]. The maximum compressive stress in the cortical bone is 190 MPa, for the trabecular bone is 5 MPa [7].

3.1. TLX3409 implant

Table 3 shows the maximum values of stress and strain with its location in each model for the type 1 model with the squared thread implants. Notice the differences between the values obtained under axial and oblique loads. All the models under axial load are below the limit of stress for cortical bone, with a max. value of 159 MPa. Under oblique load, the highest stress value is 530 MPa for the model with the implant at a 20° inclination, located at the top of the cylinder of cortical bone. Type 1 models under an oblique load of 150 N at a 45° fail in both stress and strain. The stress distribution is similar to the models under axial load, stress is maximum in the cylinder top region, but with higher values. This verifies conclusions of previous studies [12,19] regarding the oblique load being more critical than the axial load.

Table 3. Maximum von Mises stress and strain values in the model, indicating its location, and maximum values for the maxilla for type 1 models with TLX3409 implants.

			Inclination		
			0°	15°	20°
Axial	Max stress (Pa)	Model	4.91E7 (C)	1.19E8 (C)	1.59E8 (C)
		Maxilla	4.91E7	1.18E8	1.59E8
	Max strain (m/m)	Model	1.43E-2 (A)	1.51E-2 (A)	1.83E-2 (A)
		Maxilla	9.42E-3	5.58E-4	1.42E-3
Oblique	Max stress (Pa)	Model	3.53E8 (C)	4.49E8 (C)	5.30E8 (C)
		Maxilla	3.53E8	4.48E8	5.30E8
	Max strain (m/m)	Model	1.25E-1 (A)	7.89E-2 (A)	7.43E-2 (A)
		Maxilla	6.78E-2	4.22E-3	4.84E-3

Abutment (A); Cylinder (C); Implant (I); Maxilla (M)

Table 4 presents the maximum values for both axial and oblique loads for the type 2 model with squared thread implants. All models with oblique loads exceed the von Mises stress and strain limits. The critical points are located in the peri-implant region. Lower values than type 1 indicate that the absence of bone allograft, with higher elastic modulus, allows a better distribution of the stress.

Table 4. Maximum von Mises stress and strain values in the model, indicating its location and maximum values just for the maxilla for type 2 models with TLX3409 implants.

			Inclination		
			0°	15°	20°
Axial	Max stress (Pa)	Model	5.92E7 (I)	6.90E7 (M)	9.49E7 (M)
		Maxilla	3.67E7	6.89E7	9.44E7
	Max strain (m/m)	Model	7.35E-3 (A)	1.24E-2 (A)	1.13E-2 (A)
		Maxilla	9.29E-4	1.32E-3	2.81E-3
Oblique	Max stress (Pa)	Model	2.90E8 (I)	3.67E8 (I)	4.47E8 (I)
		Maxilla	1.99E8	2.18E8	1.62E8
	Max strain (m/m)	Model	7.19E-2 (A)	6.14E-2 (A)	6.11E-2 (A)
		Maxilla	5.80E-3	5.07E-3	5.50E-3

Abutment (A); Implant (I); Maxilla (M)

Most of the models under the oblique load of 150 N fail, thus, we reduce the load magnitude to evaluate the response of the bone. Table 5 shows the von Mises stress and strain maximum values for loads within 10 N to 150 N. No failure is detected below 70 N.

3.2. KDA0F3602 implant

Table 6 shows the maximum von Mises stress and strain values for the model type 1 with V-shaped thread implants. All the models with KDA0F3602 exceed the stress/strain limits and show significant problematic regions in the peri-implant region, probably associated with the thread geometry. Type 1 models show high-stress values in the top of the cortical cylinder. Also, the V-shaped thread implants generate a wider region of critical strain in specific points at the peri-implant region. The results validate the statement that squared threads dissipate more efficiently the load to the bone, which is desired to obtain more contact surface with the implant.

Table 5. Maximum von Mises stress for the maxilla for the type 2 model with a 20° incline TLX3409 implant, under different oblique load values.

Oblique load (N)	Max stress (Pa)	Max strain (m/m)
10	1.08E7	3.69E-3
30	3.24E7	1.10E-3
70	7.58E7	2.58E-3
150	1.62E8	5.50E-3

Table 6. Maximum von Mises stress and strain values in the model, indicating its location and maximum values just for the maxilla for type 1 models with KDA0F3602 implants.

			Inclination		
			0°	15°	20°
Axial	Max Stress (Pa)	Model	3.01E7 (C)	7.97E7 (C)	9.99E7 (C)
		Maxilla	3.01E7	7.97E7	9.99E7
	Max Strain (m/m)	Model	4.98E-3 (A)	1.07E-2 (C)	3.16E-2 (A)
		Maxilla	4.54E-3	1.07E-2	1.75E-2
Oblique	Max Stress (Pa)	Model	2.82E8 (A)	3.15E8 (C)	2.95E8 (C)
		Maxilla	2.79E8	3.15E8	2.95E8
	Max Strain (m/m)	Model	4.81E-2 (A)	4.52E-2 (A)	4.16E-2 (A)
		Maxilla	4.61E-2	4.29E-2	4.11E-2

Abutment (A); Cylinder (C); Implant (I); Maxilla (M)

Table 7 shows the results corresponding to the type 2 models. Some of the models under axial load, and all models under oblique loads, present strain values above 4000 microstrain. For oblique load, all the stress values exceed the limit in the bone tissue. The results show that oblique loads and a higher inclination of the implant produces a critical condition in the maxilla. The V-shape thread implants produce wider regions of critical values for both stress and strain, which means that this kind of thread geometry is less efficient.

Table 7 Maximum von Mises stress and strain values in the model, indicating its location and maximum values just for the maxilla for type 2 models with KDA0F3602 implants.

			Inclination		
			0°	15°	20°
Axial	Max Stress (Pa)	Model	7.65E7 (M)	1.09E8 (A)	1.41E8 (I)
		Maxilla	7.65E7	9.57E7	1.36E8
	Max Strain (m/m)	Model	1.29E-2 (I)	4.25E-3 (A)	1.12E-2 (I)
		Maxilla	8.9E-4	1.62E-3	7.4E-3
Oblique	Max Stress (Pa)	Model	8.21E8 (M)	4.46E8 (I)	5.2E8 (A)
		Maxilla	8.21E8	2.76E8	3.74E8
	Max Strain (m/m)	Model	7.03E-2 (M)	2E-2 (A)	3.98E-2 (I)
		Maxilla	7.03E-2	4.54E-2	1.85E-2

Abutment (A); Implant (I); Maxilla (M)

4. Conclusions

The length of the implant is not important in the stress distribution, as other studies have corroborated. The minimum diameter and variation of the material properties of the implant do not affect the response of the bone under oblique loads. Moreover, thread design is a key factor in the failure of a dental implant. Under axial load, anisotropic models with squared thread implants behave properly and do not fail by stress or strain even at inclined positions. V-shaped thread implants tend to present strain failure, which increases with the angle of inclination.

Anisotropic models without the cortical bone cylinder perform better due to the bone characteristics in the peri-implant region. The models with the new bone tissues represented with the cortical cylinder bear less load and distribute the stress and strain in a way that causes more critical conditions. This is in agreement with the recommendation made by practitioners about avoiding too much time before seeking a dental implant treatment. After a long time exposure without teeth, the bone resorbs and it would be necessary to use bone allografts which may end in a failure.

Acknowledgements

We acknowledge the support provided by Aura Lilian Suárez for the diagnostic imaging and technical information, from BioHorizons and GMI-Ilerimplants Group in Bucaramanga for the samples provided. We acknowledge the support provided by the project Capital Semilla 1742, VIE, Universidad Industrial de Santander.

References

[1] Fernandez-Barrera M A, Medina-Solís C E, Márquez-Corona M D L, Vera-Guzmán S, Ascencio-Villagrán A, Minaya-Sánchez M and Casanova-Rosado A J 2016 Edentulismo en adultos de Pachuca, México: aspectos sociodemográficos y socioeconómicos *Rev. Clin. Periodoncia Implantol. Rehabil. Oral.* **9(1)** 59

[2] Prakash S, Kinikar K, Gupta A K, Dhingra D and Rohit S 2016 Knowledge of patients regarding use of dental implants as a tool for replacement of missing teeth attending medical college in Bilaspur, India *Journal of Advanced Medical and Dental Sciences Research* **4(1)** 110

[3] Jacobs R, Van-Steenberghe D, Nys M and Naert I 1993 Maxillary bone resorption in patients with mandibular implant-supported overdenture or fixed prostheses *The Journal of Prosthetic Dentistry* **70(2)** 135

[4] Martín-Ares M 2013 *Satisfacción del paciente desdentado total y evolución clínica tras el tratamiento rehabilitador sobre implantes* (Madrid: Universidad Complutense de Madrid)

[5] Chou H Y, Jagodnik J J and Müftü S 2008 Predictions of bone remodeling around dental implant systems *J. Biomech.* **41(6)** 1365

[6] Castilla R, Forero L and González-Estrada O A 2019 *J. Phys. Conf. Ser.* **1159** 012016

[7] Baggi L, Cappelloni I, Maceri F and Vairo G 2008 Stress-based performance evaluation of osseointegrated dental implants by finite-element simulation *Simul. Modell. Pract. Theory* **16(8)** 971

[8] Pellizzer E P, Falcón-Antenucci R M, de Carvalho P S P, Sánchez D M I K, Rinaldi G A T, de Aguirre C C and Goiato M C 2011 Influence of implant angulation with different crowns on stress distribution *Journal of Craniofacial Surgery* **22(2)** 434
[9] Asdrúbal A, Graciano C and González-Estrada O A 2017 Resistencia de vigas esbeltas de acero inoxidable bajo cargas concentradas mediante análisis por elementos finitos *Revista UIS Ingenierías* **16(2)** 61
[10] Nadal E, Rupérez M J, Martínez-Sanchis S, Monserrat C, Tur M and Fuenmayor F J 2017 Evaluación basada en el método del gradiente de las propiedades elásticas de tejidos humanos in vivo *Revista UIS Ingenierías* **16(1)** 15
[11] Valencia-Aguirre F, Mejía-Echeverria C and Erazo-Arteaga V 2017 Desarrollo de una prótesis de rodilla para amputaciones transfemorales usando herramientas computacionales *Revista UIS Ingenierías* **16(2)** 23
[12] Geng J P, Tan K B C and Liu G R 2001 Application of finite element analysis in implant dentistry: a review of the literature *The Journal of Prosthetic Dentistry* **85(6)** 585
[13] Chica-Arrieta E L, Latorre-Correa F and Agudelo-Flórez S C 2010 Prótesis parcial fija: análisis biomecánico sobre distribución de esfuerzos entre tres alternativas de retención *Rev. Fac. Odontol. Univ. Antioq.* **21(2)** 150
[14] Omran M T A, Miley D D, McLeod D E and Garcia M N 2015 Retrospective assessment of survival rate for short endosseous dental implants *Implant Dentistry* **24(2)** 185
[15] Branemark P I, Zarb G A and Albrektsson T 1985 Patient selection and preparation *Tissue integrated prostheses: osseointegration in clinical dentistry* (Chicago: Quintessence Publishing Company, Inc.)
[16] Moya-Villaescusa M J and Sánchez-Pérez A J 2017 Valor pronóstico de la densidad ósea y de la movilidad en el éxito implantológico *Revista Española de Cirugía Oral y Maxilofacial* **39(3)** 125
[17] Biohorizons 2015 *Tapered HD surgical system* consulted on: http://www.dentalexpress.ma/ressource/pdf/biohorizons_tapered_internal_3m.pdf
[18] GMI Ilerimplant S L 2017 *Frontier. Implante dental de conexión interna hexagonal* consulted on: https://www.ilerimplant.com/catalogos/book/3-frontier/1-catalogos-virtuales-castellano.html
[19] Cheng H C, Peng B Y, Chen M S, Huang C F, Lin Y and Shen Y K 2017 Influence of deformation and stress between bone and implant from various bite forces by numerical simulation analysis *Biomed Res. Int.* **2017** 1
[20] Himmlová L, Dostálová T, Kácovský A and Konvičková S 2004 Influence of implant length and diameter on stress distribution: A finite element analysis *The Journal of Prosthetic Dentistry* **91(1)** 20
[21] Geng J P, Ma Q S, Xu W, Tan K B C C and Liu G R R 2004 Finite element analysis of four thread-form configurations in a stepped screw implant *Journal of Oral Rehabilitation* **31(3)** 233
[22] Macedo J P, Pereira J, Faria J, Pereira C A, Alves J L, Henriques B, Souza J C M and López-López J 2017 Finite element analysis of stress extent at peri-implant bone surrounding external hexagon or Morse taper implants *J. Mech. Behav. Biomed. Mater.* **71** 441
[23] Minatel L, Verri F R, Kudo G A H, de Faria-Almeida D A, de Souza-Batista V E, Lemos C A A, Pellizzer E P and Santiago J F 2017 Effect of different types of prosthetic platforms on stress-distribution in dental implant-supported prostheses *Mater. Sci. Eng. C* **71** 35
[24] Saab X E, Griggs J A, Powers J M and Engelmeier R L 2007 Effect of abutment angulation on the strain on the bone around an implant in the anterior maxilla: A finite element study *The Journal of Prosthetic Dentistry* **97(2)** 85