

Stress Analysis in Maxillary All-On-Four Model

Análisis del Estrés en un Modelo Maxilar del Concepto All-On-Four

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CIDADE, C. P.; OLATE, S.; POZZER, L.; PIMENTEL, M. J.; NÓBILO, M. & ALBERGARIA-BARBOSA, J. R. Stress analysis in maxillary all-on-four model. *Int. J. Odontostomat.*, 9(2):205-211, 2015.

ABSTRACT: The aim of this research was to evaluate the load distribution in tilted distal implants used in the all-on-four system. Two implant schemes were used. In both, two vertical anterior implants and tilted posterior implants were installed, one group with an angulation of 15° and another with an angulation of 35°. The implants were installed together with a bar binding them all in a photoelastic model obtained from a replica of an edentulous maxilla. In this model, loads were produced in the sector of the bar cantilever, the abutment of the tilted implants and over the four implants using devices specially designed for this purpose. The bands were recorded with a digital camera, and the qualitative and quantitative analyses were carried out by means of student's t-test and the Mann-Whitney test in Biostat v. 5.0, considering a level of $p < 0.05$ to establish a statistically significant relation. In the qualitative analysis, the implant with 35° presented the greatest amount of stress on the cantilever forces at cervical level. The quantitative studies showed fewer differences in all aspects assessed, although significant differences were observed between the two systems when loads were applied at cantilever level. It can be concluded that there are minimal differences in the stress distribution when comparing implants with angulations of 15° or 35°. However, there is a greater concentration of stress at the cervical level in implants tilted to 35°.

KEY WORDS: tilted implants, photoelastic stress analysis, maxillary implants.

INTRODUCTION

The rehabilitation of edentulous maxillae is a constant challenge. In cases with significant atrophy, tilted implants have gained acceptance based on the use of longer implants, because these can anchor into a greater cortical bone surface and thus reduced the distal cantilever (Krekmanov *et al.*, 2000). The use of tilted implants restricts the use of bone grafts and decreases surgical morbidity, with an over 90% success rate (Mattsson *et al.*, 1999).

Some research showed that rehabilitation in the maxillary all-on-four scheme using anterior vertical and posterior tilted implants allows survival over 95% (Maló *et al.*, 2012a; Balshi *et al.*, 2014). Likewise, this scheme installed in bone area with considerable bone deficiencies, post-extraction alveoli, fenestrations and "non-ideal" bone conditions generally presents a high success rate, with a bone loss of up to 1.6 mm at cervical level at 3 years of follow-up (Maló *et al.*, 2012b).

In fact, the use of tilted implants parallel to the anterior wall of the maxillary sinus has been proposed as a conservative solution for the treatment in atrophic maxilla (Krekmanov *et al.*).

On other hand, Maló *et al.* (Maló *et al.*, 2012a) in tilted implant, showed cervical bone loss close to 2 mm at 5 years of follow-up, while Crespi *et al.* (2012) reported that the fixed prosthesis had no influence on bone loss or implant stability. Although clinically tilted implants are stable, the degree of angulation may be associated with bone loss (Markarian *et al.*, 2007). Recent information showing that cantilever length could be significant in marginal bone loss and more important than the tilted degree of implant (Malhotra *et al.*, 2012); in the same direction, the length of the implant could be important in the load distribution in an "all on four" model (Özdemir Dogan *et al.*, 2014). The degree in distal implant influence in the load distribution, showing that increase in the tilted

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degree of this implant is proportional to the increase in the stress concentration (Sannino, 2015).

The aim of this research was to identify the stress generated after load application on tilted distal implants in the all-on-four system, comparing two different degrees of angulation with the same implant characteristic and the same cantilever length.

MATERIAL AND METHOD

From a polyurethane skull with edentulous maxilla (Nacional Ossos Ltda.®, Sao Paulo, Brazil) a replica of the maxilla was made with Araldite GY 279 photoelastic resin and Aradur 2963 catalyst (Araltec® Produtos Químicos Ltda – Guarulhos, São Paulo, Brazil). These replicas had implants with an external-hex connection, cylindrical body and conical apex, with a surface treatment (Conus®, INP, Sistema de Implantes Próteses Nacionais), using the following configuration:

Group 1: edentulous maxilla with two implants in the anterior area (3.5 x 10 mm) and two distal implants (3.5 x 15 mm) tilted 15° with a 10mm cantilever in the bilateral posterior zone. The distance between the midpoint of the two anterior implants was 12 mm and the distance between each central implant and the posterior implant (in each side) was 17 mm.

Group 2: edentulous maxilla with two implants in the anterior sector (3.5 x 10 mm) and two distal implants (3.5 x 15 mm) tilted 35° with a 10mm bilateral cantilever. The distance between the midpoint of the two anterior implants was 12 mm and the distance between each central implant and the posterior implant (in each side) was 19 mm.

Implant angulation and metallic bar. Implant angulation was achieved using tilted positioning guides for 15° and 35° implants, arriving at the preparation of two master models for each all-on-four system.

For each initial prototype, the position was recorded with condensation silicone to then obtain a plaster matrix with the implant analogs in position. The matrix was used to make the bar that was installed on the implants in group 1; the same methodology was used for group 2. This system standardized the bar and the position of the 4 implants in each of the groups. Three sample units were obtained for each group.

Photoelastic model and sample. The photoelastic models coincide with previous published paper working in a mandible model (Kim *et al.*, 2011). From the maxilla model with implants already created, a negative model was obtained, made in silicone (ASB 10 blue silicone rubber - POLIPOX®), handled according to the manufacturer's instructions. This model followed the morphology of the edentulous maxilla and on this silicone model the duplicate bar was incorporated together with the abutment-implant complex (for each sample), which was stabilized with lateral adhesives to avoid movement.

Then the Araldite GY 279 photoelastic resin and Aradur 2963 catalyst (Araltec® Produtos Químicos Ltda – Guarulhos, São Paulo) were mixed at high pressure with 588.4 N/cm² for 3 minutes to remove the bubbles. Then, using a pipette, the photoelastic resin was added to this silicone model and subsequently maintained at high pressure for 24 h and then removed for analysis. This scheme was performed on 6 sample units.

Photoelastic analysis. A circular polariscope was connected to a digital camera (Canon EOS Rebel XS SLR Digital, Canon EF 100 mm f/2.8 macro USM lens) that could record the bands during the load phase. Focal distance and standardized conditions were maintained throughout.

The applied load was vertical and progressive until reaching 4.9 N (With 4.9 N load, was observed in the pilot study, that all the four implants were loaded in all the cervical and apical area and were possible the measurement for all implant body), and was applied to 1) the posterior sector of the bar (cantilever), 2) between the two central implants, 3) on the abutment (bilaterally) and 4) on a specific resin platform that included the four abutments (Was designed an arch form resin with a 5 mm high, installed in contact with the all 4 abutment over the bar; the load was applied on this resin system in the central point). Each load was applied in different implant-model and the images of the fringes were obtained for the cantilever region and the bilateral distal implant, recorded for all samples.

The images were contrasted on a 25 mm x 22 mm x 10 mm index plate. With this system, standardized points were obtained to analyze the maximum shear stress (τ) using the Fringes® program in the MatLab® environment. For this test, the optical constant of 0.38 N/mm was used because in the pilot study this was the better response to analysis.

Data analysis. For the sectorial analysis of the implants, they were divided into two areas, the upper part being called the cervical and the lower part the apical sector. This division was in the middle of the length implant. A point analysis was made with a standardized 2.0 mm reticular mesh (in the photography). For that, all points between the intersection of lines showing fringes were selected (from the load distribution).

All these points were introduced into the model to observe fringes quantitatively and the distance from the implant surface. A qualitative analysis was performed to identify the place where the bands began and spread (stress), and their distribution. The quantitative analysis was performed by examining the mesh points and bands using the student's t-test and the Mann-Whitney test in BioEstat v. 5.0, considering a level of $p < 0.05$ for statistical significance.

RESULTS

The test was applied with no problems. The analyses in this research was concentrated on the study of the distal implants; thus, when the load was applied at cantilever level, a greater concentration of stress was observed in the apical sector of the implants at 15° and 35° (Figs. 1 and 2). The implant at 35° presented stress throughout the entire implant, whereas the one at 15° exhibited a lower concentration of stress.

When the load was applied at occlusal level, on a specific platform to capture the force in all the implants, a limited stress distribution was observed in the implants at 15° and a greater stress distribution in the implants at 35°, characterized by the green color of the apical area.

Stress on the implants with the load at the level of the abutments of the tilted implant revealed a greater stress throughout the entire implant at 35° compared to the 15°, which exhibited stress basically in the apical sector (Figs. 3 and 4).

In the quantitative analysis of the results from the cantilever zones (load on the posterior sector of the bar), significant differences were observed in the apical region ($p = 0.03$), whereas in the other areas no differences were observed. When the results were compared after load application on the abutments, no significant differences were observed, and when the load was applied in the occlusal region there were significant differences in the cervical region of the 15°

systems compared to the 35° systems ($p = 0.04$) (Table I), being higher in the implants at 35°.

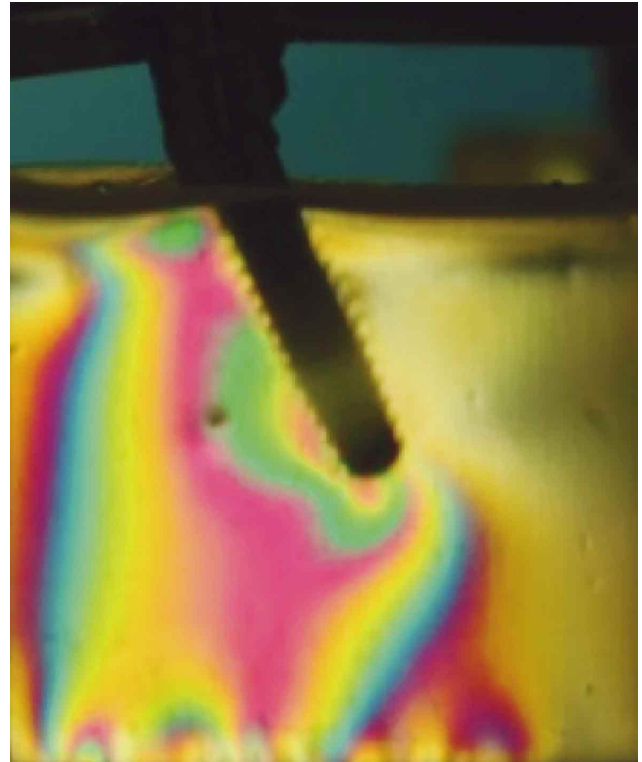


Fig. 1. Stress distribution in implants tilted 15° when applying the load in the posterior sector of the bar (cantilever).

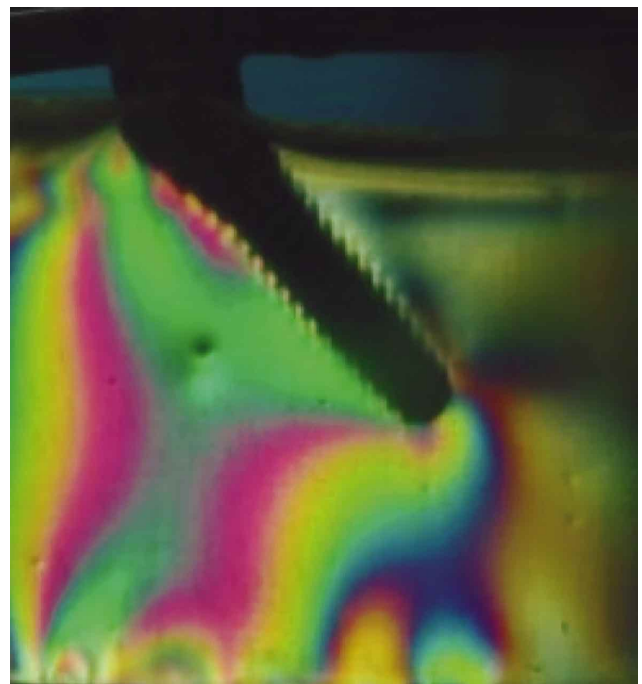


Fig. 2. Stress distribution in implants tilted 35° when applying the load in the posterior sector of the bar (cantilever).

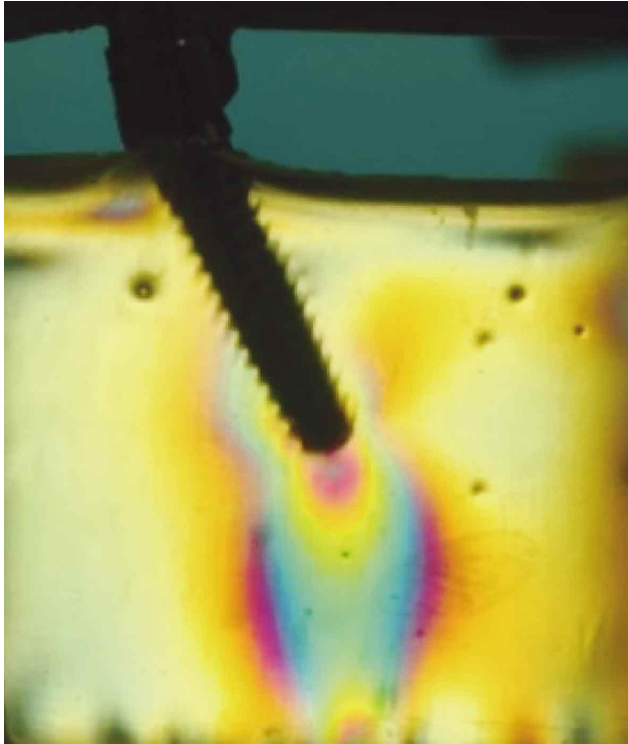


Fig. 3. Stress distribution in implants tilted 15° in the application of a load on the abutment, showing a concentration of stress at apical level.

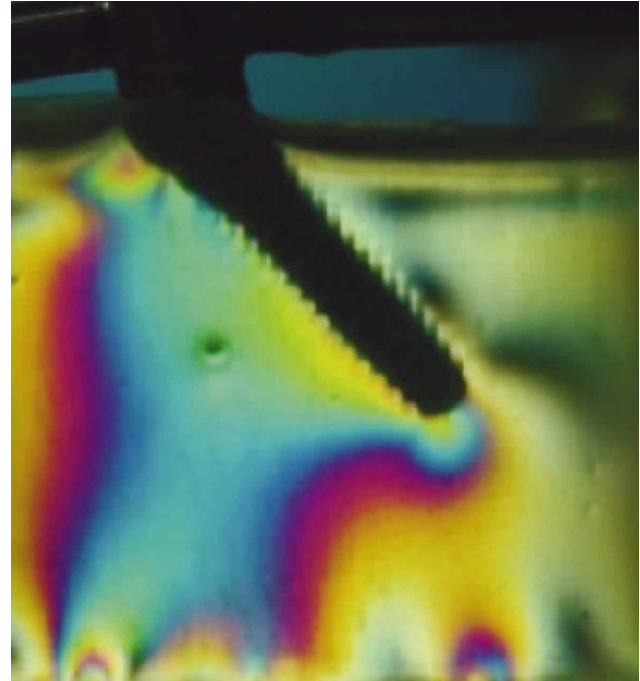


Fig. 4. Stress distribution in implants tilted 35° in the application of a load on the abutment, showing a concentration of stress at apical level.

The sectorial analysis of the implants also showed differences. For each of the loads, significant differences were observed when the load was applied

in the cantilever sector. The other loads showed no differences in terms of cervical or apical sectorial analysis (Table II).

Table I. Stress distribution on the implants at 15° and 35° at cervical and apical level with the different loads applied.

Area for Load Application	Stress	Implant 15°	Implant 35°	p
Cantilever	Total	485.5±64.7	430.2±126.7	0.36
	Cervical	274.8±61.8	262.6±97.1	0.8
	Apical	210.6±24.5	167.6±36.8	0.03 *
Distal Abutment	Total	352.9±60.6	326.8±50.1	0.43
	Cervical	180.9±55.8	181.4±46.7	0.9
	Apical	172.0±11.4	145.3±22.4	0.02
Occlusal Platform	Total	208.9±24.8	233.0±32.7	0.18
	Cervical	101.9±6.2	128.9±22.9	0.04 *
	Apical	106.9±24.0	104.0±29.0	0.8

*= Statistically significant.

Table II. Comparison of stress at cervical and apical level in the different loads.

Area for Load Application	Stress	Implant 15°	p	Implant 35°	p
Cantilever	Cervical	274.8±61.8	0.03*	262.6±97.1	0.04*
	Apical	210.6±24.5		167.6±36.8	
Distal Abutment	Cervical	180.9±55.8	0.8	181.4±46.7	0.11
	Apical	172.0±11.4		145.3±22.4	
Occlusal Platform	Cervical	101.9±6.2	0.6	128.9±22.9	0.12
	Apical	106.9±24.0		104.0±29.0	

*= Statistically significant.

DISCUSSION

The great advantage of the photoelastic models lies in that they provide us the location and pattern of the stresses (Barbosa *et al.*, 2007), whereas the great disadvantages of this model are the homogeneity and the isotropicity of the material, completely different when compared to peri-implant tissues, which present different moduli of elasticity according to the region, whether soft tissue or bone tissue (Begg *et al.*, 2009). Nevertheless, it is an adequate method of comparison that isolates multiple variables in terms of patients with total rehabilitation on implants. The cantilever length was the same in both, group 1 and group 2, because in these instances the tilted degree was analyzed with a minor influence of the cantilever as a variable in load distribution. The same implant in the same prosthetic device but in different degree (15° or 35°) could be more related to the aim of this research.

Using a finite element analysis, it has been observed that single implants that are tilted increase the stress distribution on the adjacent bone compared to those installed vertically (Bevilacqua *et al.*, 2010); additionally, the abutment angulation has also shown important differences in the stress distribution when different bone qualities and different angulations are compared (Arun Kumar *et al.*, 2013).

Our results show some differences between the degree of angulation and the stress distribution, increasing at 35°. Although the qualitative differences were clear, the quantitative differences were observed in only two of the aspects evaluated. Implant angulation, working in conjunction with vertical implants, may be the reason for the efficiency of the system, where clinical trials have shown success rates over 95% (Maló *et al.*, 2005).

In a solitary implant, the stress around the tilted implant shows three to five times higher than axial implant in vertical load (Cehreli *et al.*, 2004). In multiple implants with a splint structure, as the present study, the complete arch is working in the load distribution and can reduce the bending effects of the tilted implant.

Kim *et al.*, carried out research in mandibular full arch using four implant in a photoelastic model; they concluded that maximal stress in implant increased with increased cantilever length; the tilted model using distal implant in 30° showed lower value of stress than the axial model (without tilted implant)

showing biomechanical advantage in tilted implant. They concluded that the distal tilted implant, in this conditions, did not increase the stress in the distal crest under three loading conditions.

Silva *et al.* (2010), compared six vs. four implants in the maxillary bone with a three dimensional finite analysis, using a 45° tilted position in the distal implants; with regard to the maximum stress values, there were lower values in the six implant model when compared to the four implant model, related to the presence of an implant in the canine position (in the six implant model); however, the stress location and distribution patterns were very similar in the two models.

Reducing the size of the cantilever as well as the designs made on the fixed prosthesis seems to be important in the stability of the treatment (Zampelis *et al.*, 2007). In other research (Rubo & Capello Souza, 2010) was observed that the increase in stress was proportional to the size of the cantilever, which would be of benefit when using tilted implants. Silva-Neto *et al.* (2013) reported that tilted implants exhibited high stress in the finite analysis, although these is a positive influence on decreasing the load in some zones because the reduction in the distal cantilever area. Begg *et al.*, also reported that the angulation of the distal implants is greater on the cervical load, with similar results to our observations, demonstrating that implants at 45° display high stress levels. Our results support the notion that the greater angulations show a high risk of excessive cervical loads, although not sufficient statistical differences were presented to provide more precise results.

Another aspect that may be relevant in this analysis is the type of connection; de Faria Almeida *et al.* (2014) reported that the external-hex connection presented a greater stress distribution than any other type, and the implant angulation was less important than its prosthetic connection. On the other hand, Monje *et al.* (2012) published a meta-analysis with an assessment of the clinical results of cervical bone loss from tilted implants, concluding that these might not be statistically associated with implant angulation.

Clinically, a long-term study found no significant differences in implant survival in a comparison of complete maxillary prosthesis supported by four or six vertical implants (Brånemark *et al.*, 1995). In this research, 35° was proposed because clinically is possible to

adequate this angled in the bur and hand piece by intraoral approach to obtain 35°; 45° position in maxilla will be difficult to insert in a regular condition. In this research, 15° is very similar to 35° in load response, but 35° tilted implant permit 3 mm more distal abutment than 15° and this situation could be clinically interesting.

It may be concluded in this research that there are minimal differences in the stress distribution when comparing implants with angulations of 15° or 35°. However, there is a greater concentration of stress at cervical level implants with 35° than in those with 15°, which present a greater amount of apical stress.

CIDADE, C. P.; OLATE, S.; POZZER, L.; PIMENTEL, M. J.; NÓBILO, M. & ALBERGARIA-BARBOSA, J. R. Análisis del estrés en un modelo maxilar del concepto all-on-four. *Int. J. Odontostomat.*, 9(2):207-211, 2015.

RESUMEN: El objetivo de esta investigación fue evaluar la distribución de cargas en implantes angulados distales utilizados en el sistema "All-On-Four". Dos esquemas de implantes fueron empleados. En ambos, dos implantes verticales en el área anterior y dos implantes angulados en el sector posterior fueron instalados, utilizando angulaciones de 15° y 35° o en estos últimos. Los implantes fueron instalados de forma conjunta mediante una barra unida al sistema de resina fotoelástica obtenida de una replica de una maxila edéntula. En este modelo, las cargas fueron producidas en el sector del cantiléver de la barra, el pilar del implante angulado y, mediante un sistema genérico, sobre la totalidad de los implantes. Las bandas de estrés fueron reconocidas en una cámara digital donde los análisis cualitativos y cuantitativos fueron realizados utilizando las pruebas t de Student y Mann-Whitney en el programa computacional Biostat v. 5.0, considerando un valor de $p < 0,05$ para establecer diferencias significativas. En el análisis cualitativo, los implantes con 35° presentaron una gran cantidad de estrés en el área de cantiléver, principalmente a nivel cervical. Los estudios cuantitativos mostraron limitadas diferencias en todos los aspectos, aunque diferencias significativas fueron alcanzadas cuando se compararon ambos sistemas después de la carga a nivel del cantiléver. Se puede concluir que hay diferencias menores en la distribución de estrés cuando se comparan implantes dentales con angulación de 15° y 35°. Sin embargo, existe una mayor cantidad de concentraciones de estrés a nivel cervical en los implantes con 35° de angulación.

PALABRAS CLAVE: implante angulado, análisis de estrés fotoelástico, implantes maxilares.

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Received: 11-03-2015

Accepted: 22-04-2015