STRAIN DISTRIBUTION ON ORAL IMPLANTS WITH DIFFERENT DESIGNS OF CONNECTIONS

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Abstract. *Nowadays, oral implants can be fabricated with different types of connections. These connections are usefull for helping the insertion of the implant and as anti-rotational element of the abutment. This work aims to analyze stress distribution over dental implants. The implants were fabricated with the same external design, differing only at the connections: external hexagon (EH), internal hexagon (IH), internal conical (IC) and one without connection to the abutment (one piece, OP). The samples were immersed in photoelastic models and submitted to two compressive loads: (1) axial - load 1; and (2) 6.5mm away from the center – load 2. Points over the implants were analyzed, in those the maximum shear stresses were determined. Graphics were made by the analyzed points and their areas were calculated in the two loads situations, for the total implant body and only at the platform region. It could be concluded that for load 1 the connections did not present differences for the stress distribution over the implants. But for load 2, IH presented the lowest values, and EH presented the highest, in all regions analysed.*

Keywords: *Biomechanical, oral implants, connections, stress analysis, photoelasticity.*

1. Introduction

The original models of dental implants are fabricated in two basic pieces. One of them is a screwed base which is inserted into bone, denominated implant. The other piece fits over the superior platform of the implant staying exposed to the oral environment and is called abutment. The abutment is used as base to the dental prosthesis being fixed to the implant by the use of screws, denominated abutment screw. Today, there are many possibilities matches between implant and abutment searching for a better adaptation and as anti rotation component of the prosthesis (Binon, 2000).

Binon (2000) and Finger, Castellon and Elian (2003) related that in the North American market there was close to 20 different types of connection abutment/implants. According to some authors (Binon, 2000; Taylor and Agar, 2002; Taylor, 2003), between the many existent connections, the internal connection would be an evolution of the classic external hexagon connection, which was developed in the first implant osseointegrated system, the Brånemark system. Internal connections could make possible a minor occurrence of screw loosening of the abutment screw (Finger, Castellon and Elian, 2003; Taylor and Agar, 2002; Norton, 1997; Çehreli, Akça and Iplikçioglu, 2004) and they could absorb better external loads (Norton, 1997; Çehreli and Iplikcioglu, 2002) from the dental occlusion. Their geometry could make possible a stress distribution around the implant more homogeneous in relation to the external hexagon implant (Hansson, 2003), decreasing stresses over the crest bone. Beyond this, Taylor (2003) believes that, maybe, the separation between implant and abutment will not exist in the next generation of oral implants and they will be likely one pieces units and it would decrease the possibility to cause screw mechanical failures. Çehreli, Akça and Iplikçioglu (2004) comment that, in this case, there would be a significant resistance to implant fracture, principally when comparing to implants with internal connections, which have internal walls of less thickness.

Dental implants present a bone loss at a rate of 0.9mm in the first year of use and 0.1mm in each subsequent year (Goodacre *et al*., 2003). A probably reason for this phenomenon could be a stress concentration over the marginal crest bone (Chun, *et al*. 2002; Çehreli and Iplikçioglu, 2002; Hansson, 2003; Eskitascioglu *et al*., 2004; Kitamura *et al*., 2004). Such stresses, added to the masticatory cycles, could lead to local bone microfractures and consequently hard tissue loss (Pilliar *et al*., 1991; Hoshaw, Bruski and Cochran, 1994; Brunski, Pulleo and Nanci, 2000; Ducyck *et al*., 2001; Chun *et al*., 2002). This tissue response is determinate by the type of the fixed implant, magnitude of the stress and quality of the surrounding bone (Hoshaw, Bruski and Cochran, 1994; Brunski, Pulleo and Nanci, 2000; Duyck *et al*., 2001; Eskitascioglu *et al*., 2004). Then the internal connections could lead to lesser bone loss because of their capacity to decrease stress over the crest marginal bone (Norton, 1997; Hansson, 2003).

According to Taylor, in 2003 the annual sells of oral implants in the American market was close to 300 million dollars and Binon attested that in 2000 there was world wide close to 125 implants companies. This competition leads to marketing strategies which not always are based on scientific documentations (Binon, 2000). This added to the many options of implants on the market lead the clinicians to an uncertainty of which system they should use.

This work purposes to analyze comparatively the quantity and quality of the stress gradient generated on dental implants with the same geometry, differing only at the implant/abutment connection type: external hexagon, internal hexagon, internal conical and an one piece implant. The stress gradient will be evaluated over the implants contour using an experimental technique named plane photoelasticity transmission. The study realizes quantity and quality analyses of the stress levels giving to clinicians the information of which of those systems have a better characteristic relative to the distribution of the stresses gradients at the region next to the implants, indicating which of the systems might have a minor potential for bone loss.

2. Material and Methods

Titanium pieces like implants were fabricated with same dimension, differing only at the implant/abutment interface: external hexagon, internal hexagon, internal conical and a piece without connection, with the two components machined together resulting in a one piece (Fig. 1). Four implants were made to each group: external hexagon (EH), internal hexagon (IH), internal conical (IC) and one piece (OP). In this way, at the moment that the abutments were screwed to the implants there were similar bodies. Each implant had 13mm of height and 4.3mm of diameter, while the abutment had 11mm of height. Those pieces were fabricated without the presence of the external screws because this work aims to evaluate the stresses levels generated only from the different connections, then, possible variations between the pieces were reduced.

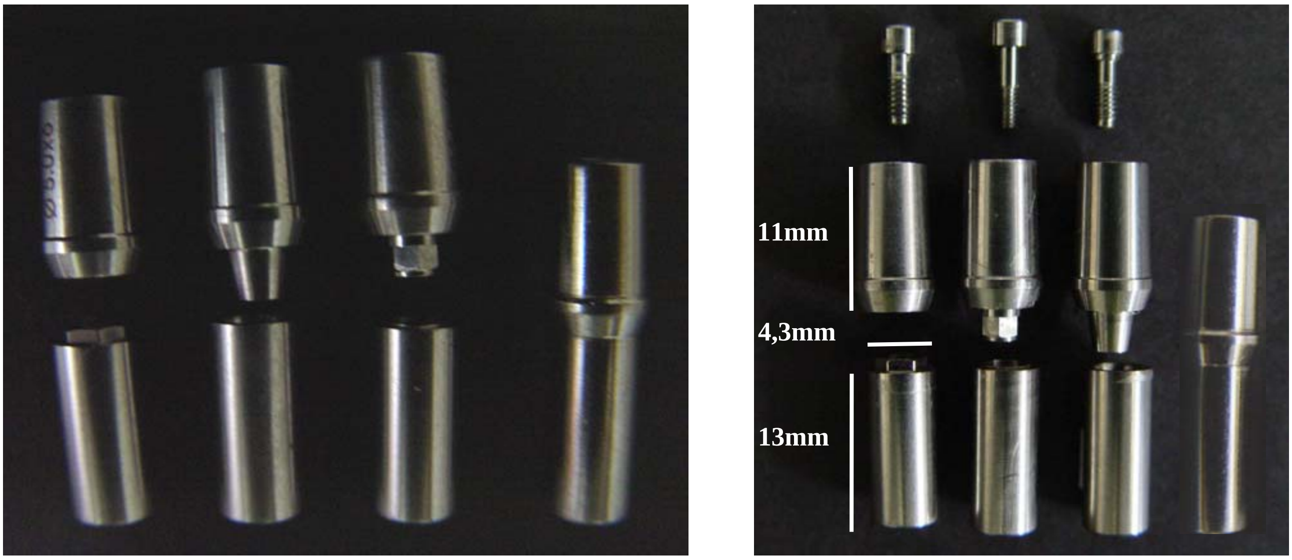


Figure 1. Implants and used abutments.

Photoelastic blocks were made with the implant/abutment inside it. The implants had 12mm of its height immersed in the photoelastic resin (Polipox Indústria e Comércio Ltda, São Paulo, Brazil). After, each model was evaluated on the vertical polariscope (Fig. 2) of the Mechanical Project Laboratory at the School of Mechanical Engineering, University of Uberlândia, to verify the possible presence of a process called “border effect” (Dally and Riley, 1978). A circular base used for applying load was fitted over the abutment. Each photoelastic model was inserted on a device for load application. That device had an active point united to a Kratos load cell (São Paulo, Brazil) of 50 Kgf (Fig. 3). Figure 2 shows all the experimental display fixed in the vertical polariscope. After that there was applied two types of compressive load over the models: one axial to the implant on the center of the circular base in the value of 1.5 Kgf (load type 1), and other parallel to the fixture, but dislocated 6,5mm to the center of the circular base in the value of 0.75 Kgf (load type 2). The values of load applied were compatible to the used resin and they were in levels that made possible a better reading of the fringes. Figure 4 presents a diagram of how the loads were applied.

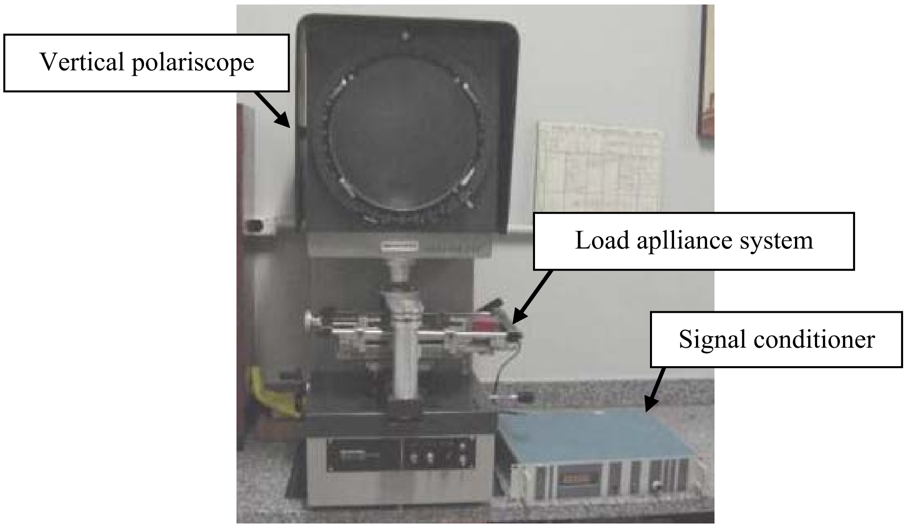


Figure 2. Experimental display.

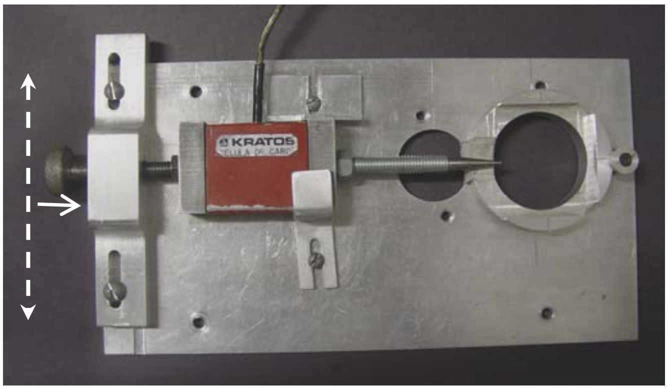


Figure 3. Load aplliance system. Arrows represent the possible movements of the load point.

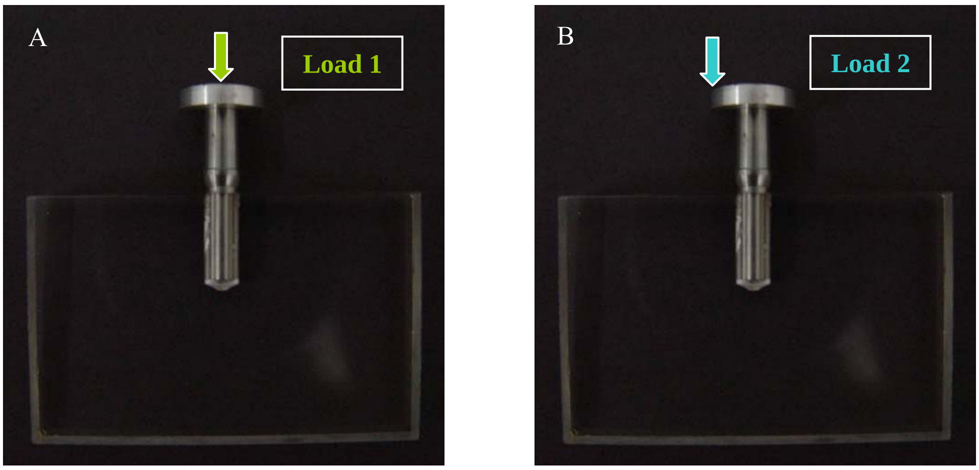
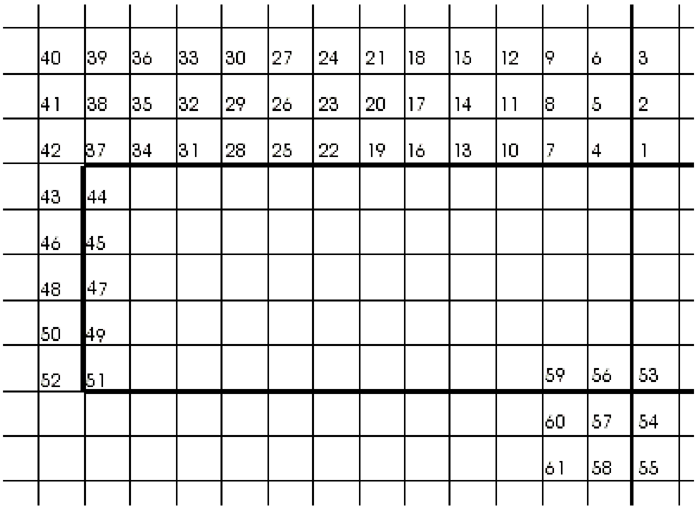


Figure 4. Diagram of the photelastic models under load 1, at the center of the implant measuring 1.5 KgF (A), and load 2, 6.5mm away from the center measuring 0.75 KgF (B).

The strain levels were evaluated at 61 points to load 2 and at 46 points to load 1, these points were distributed over the area next to the implants contour. Figure 5 shows the configurations of these points. 46 points were chosen with the purpose to analyze all the phenomenon around the implant body, which was similar in the upper and lower side of each piece (Fig. 6). 61 points were used for load 2 because in this situation the stress pattern was different in both sides of the implants, and analyzing 61 points it could be possible to evaluate the apex, marginal area and the main lateral area with compression (Fig. 7). A transparent paper with the impression of the points was fixed on the out screen of the polariscope (Fig. 5) looking for a standard reading of them. To load 1 less points were read because the fact that the stress patterns were presented symmetric in relation to the axis of the implants (Fig. 6).



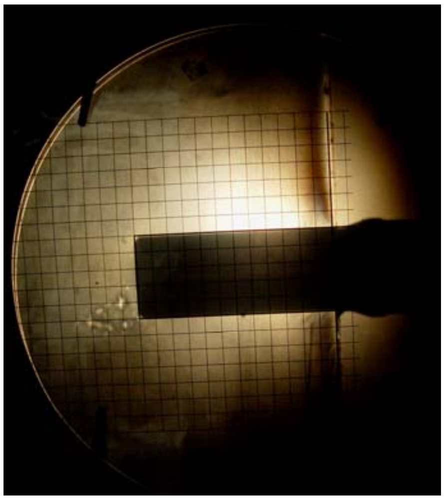


Figure 5. Rail used to the reading and implant positioned in the vertical polariscope.

Fringes orders (N) of each reading point of the analyzed models were determinate by the Tardy compensation method (Dally and Riley, 1978). The optical constant of the material (k_σ) was determinate by a calibration method (Dally and Riley, 1978), being at the order of 0.25 N/mm. Equation (1) represents the "optical stress law" (Dally and Riley, 1978), and it was used to determine the individual maximum shear stress (τ) of all analyzed points.

$$\tau = \frac{\sigma_1 - \sigma_2}{2} = \frac{K\sigma\, N}{2h} \qquad (1)$$

In Equation (1), h represent the model thickness and σ_1 and σ_2 are the main stresses.

Figures 6 and 7 show the fringes patterns obtained to the four analyzed connections considering the load type 1 and 2. Figures 8 and 9 show the medium values of the maximum shear stresses determined on the EH, IH, IC and OP implants.

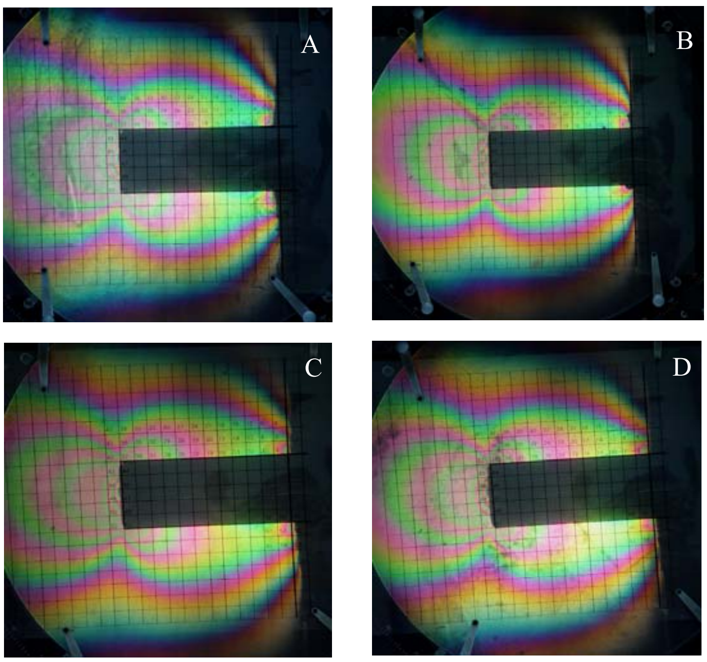


Figure 6. Pieces with different connections (A. EH, B. IH, C. IC and D. OP) under load 1.

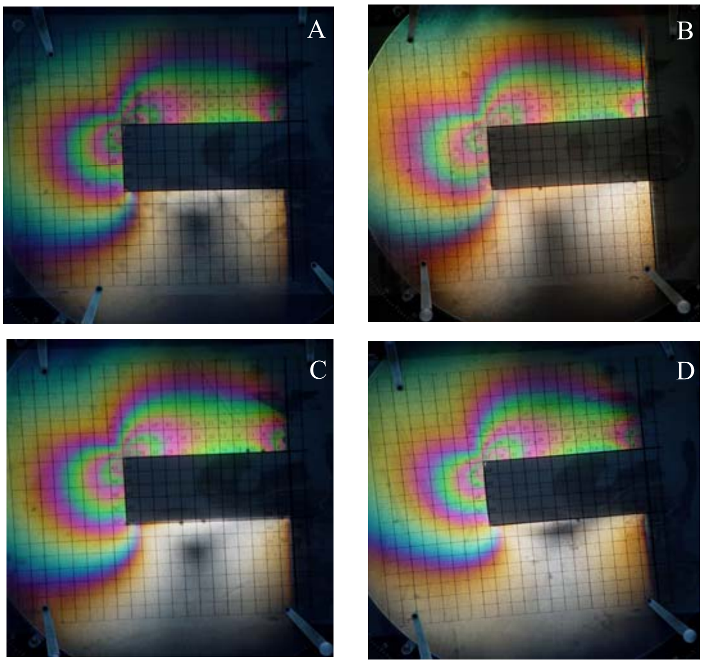


Figure 7. Pieces with different connections (A. EH, B. IH, C. IC and D. OP) under load 2.

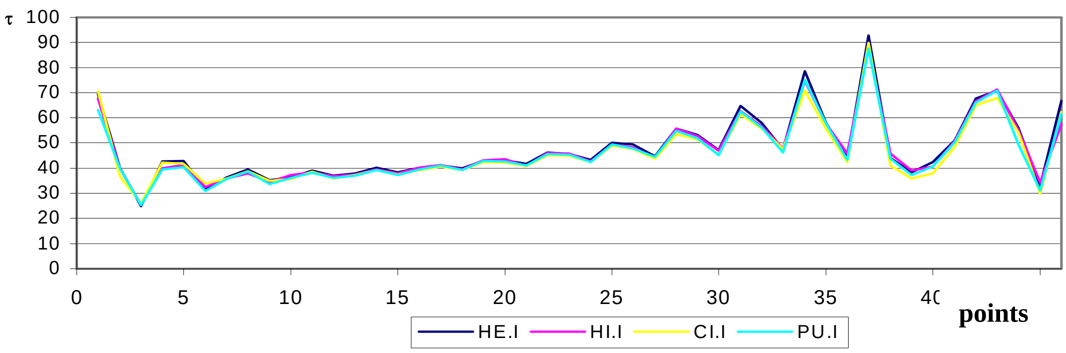


Figure 8. Medium values of maximum shear stress to load 1.

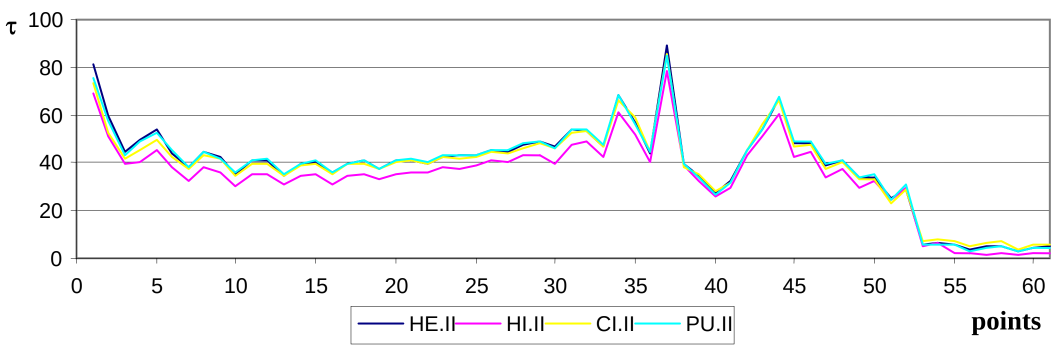


Figure 9. Medium values of maximum shear stress to load 2.

It could be observed that the figures presented a similar pattern of behavior to the analyzed points. An energy criterion was determined to increase the sensibility of the readings considering the area of the graphics (points x maximum shear stress). Table 1 presents those energy levels found for load 1 and 2.

Table 1. energy levels found for load 1 and 2.

Connections	Load 1	Load 2
EH	2121,6	2336,2
IH	2094,7	2068,7
IC	2053,2	2294,2
OP	2062,5	2336

The energies were normalized, considering the minor value as reference. The results were evaluated with statistical tests (ANOVA, Kruskal Whallis H, t student, Mann Whitney U) with the SPSS computer program.

The bone loss process occurs principally at the marginal crest near to the implant platform. Because of this another analysis was purposed separately, an analysis of the first nine points of the rail, which corresponds to the critical situation in the present study.

3. Results

Firstly, ANOVA statistical test was performed with the purpose to verify the possible existence of significant differences between the measures of the calculated energies of the four groups's samples, to load 1 and 2, considering the analyzed points of each load, in situations of normal distribution of samples, but when the distribution presented non normal, a Kruskal-Wallis H test was performed. Mann-Whitney U or t de Student were performed, depending of the results distributions, to discover eventual differences between the samples. The significant level was established to be 0.05 to a bilateral proof. To the descriptive statistic analysis of the frequency of the samples Skewness and Kurtosis tests were performed.

There were not found to be significant statistical difference ($p<0.05$) for load 1 in any of the two purposed analysis. But for load 2, statistical differences were found ($p<0.05$) in both situations. When evaluating the energy levels of all implant body, differences were found between the IH group, with the lowest values, to the others, which did not present differences between themselves. And, when evaluating the energy level of the first nine points a difference was found between the IH group, still with the lowest values, and EH and OP. Table 2 presents the load 2 results over all the implant body.

Table 2. Comparison of the load 2 results (normalized values).

EH	IH	IC	OP
1.1293	1	1.109	1.1293
12.93%	0%	10.90%	12.93%

Internal hexagon implants exhibit the lowest stress level for the dislocated load, type 2. EH and OP implants presented the same values, being those 12.93% higher than IH. Table 3 details the results corresponding to the marginal crest, points 1 to 9, under load 2.

Table 3. Comparison of the load 2 results in relation to points 1 to 9 (normalized values).

EH	IH	IC	OP
1.1736	1	1.0945	1.1520
17.36%	0%	9.45%	15.20%

The differences between the connections were higher for the Table 3, in that the lowest stresses levels were for the IH group and the higher levels (17.36%) were for EH.

3. Discussion

Haraldson, in 1980 employed, for the first time, photoelasticity with dental implants demonstrating the importance of their geometry to the transfer of stress for the circulating bone. Iplikçioglu *et al*., 2003 found difference between the results of a finite element analysis and an experimental analysis, demonstrating that numerical analysis only, could not represent the occurred strains at the implant/abutment connection region, critical area of the present study. A complicate factor of a numerical analysis is the specification of the contour condition (Çehreli, Akça and Iplikçioglu, 2004) because a perfect union between implant and abutment would not be realistic (Çehreli, Akça and Iplikçioglu, 2004; Iplikçioglu *et al*., 2003).

The geometry of connections influenced on the stresses generated in the material circular of the implant, principally to load 2. In this case, the IH implants presented the lowest stresses gradient values over the total implant body, followed by the IC group with values higher than IH. Comparatively, the EH and OP showed equal results (12.93%). Internal hexagon group presented statistical differences ($p<0.05$) with the others groups, because its value was the lowest. Either for the analysis of the first nine points (crest region), in that, to load 2 the stresses levels of IH were the lowest, while the EH connection had the highest stresses levels with a stress concentration of 17.4% in relation to IH. IH, the reference value, presented statistical differences ($p<0.05$) in relation to EH and OP. The connections IH and IC were not statistically different in relation to the stress levels. The connections EH, OP and IC presented similar results too.

The importance of the connections was not high to load 1, and without statistic differences ($p<0.05$) for all analysis. A similar pattern of stress distribution was presented for this load type, independent of the connection.

According to Hansson (2003) there is a relationship between internal wall thickness and stress distribution, then, fine internal wall could result in small values of generated stress. In the present study the implants platforms were one millimeter over the superior surface of the photoelastic models and the internal hexagon and internal conical implants had finer internal wall thickness than the external hexagon and one piece. This, it could explain the fact that the IH and IC groups presented the minor stresses levels in relation to the maximum shear stresses localized on the neck of the implants.

Çeherli, Alkça, Iplikçioglu (2004) either realized a finite element analysis comparing to equal implants, differing only at the fact that one implant had internal conical connection and the other was one piece, not finding statistical differences of the stress distribution surrounding the samples, such for horizontal load as for vertical load. In the present study, this results agreed partially, because the implants with internal conical connection presented minor values than the one pieces under dislocate load (load 2), although they were not statistically different ($p<0.05$).

4. Conclusion

Significant statistical differences were not found for load 1 between the samples in any of the purposed situations ($p<0.05$). But for load 2, a significant statistical difference was found ($p<0.05$) between the IH samples and the others groups. The group IH presented the lowest maximum shear stresses values, followed by IC group, and OP and EH groups, which presented the same values.

For load 2, in relation of the first nine points stress distribution, a significant difference was found ($p<0.05$) between the IH and EH and OP. There were not found any statistical differences between the internal conical, external hexagon and one piece. The lowest values were found in IH implants, followed by IC (9.45%), OP (15.20%) e EH (17.36%), higher than the first. There were significant differences between the IH group and the EH, IC and OP groups in the analysis of the energy levels of all implant body. And those did not presented statistical difference between one another.

Until this moment the phenomenon which starts the marginal bone loss process is still unknown, in relationship to the stress level, it could not be affirmed that the difference in stress levels obtained between the analyzed connections, principally to load 2, indicate that a connection IH type would be better than the others connections types, even under real load condition over the implants.

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5. References

Binon, P., 2000, "Implants and components: entering the new millennium. Int J Oral Maxillofac Implants", Vol. 15, No. 1, pp. 76-94.

Brunski, J. B.; Puleo, D. A. and Nanci, A., 2000, "Biomaterials and biomechanics of oral and maxillofacial implants: current status and future developments." Int. J. Oral Maxillofac. Implants, Vol. 15, No.1, pp.15-46.

Çehreli, M. C., Akça, K. and Iplikçioglu, H., 2004, "Force transmission of one- and two- piece Morse-taper oral implants: a nonlinear finite element analysis." Clin Oral Impl Res, Vol. 15, No. 4 , pp 481-489.

Çehreli, M. C.and Iplikcioglu, H., 2002, "In vitro strain gauge analysis of axial and off-axial loading on implant supported fixed partial dentures." Impl Dent, Vol 11, No. 3, pp. 286-292.

Chun, H. –J. *et al*., 2002, "Evaluation of design parameters of osseointegrated dental implants using finite elements analysis." J. Oral Rehabil., Vol. 29, No. 6, pp. 565-574.

Eskitascioglu, G. *et al*., 2004, "The influence of oclusal loading location on stresses transferred to implant-supported prostheses and supporting bone: A three-dimensional finite element study." J. Prosthet Dent., Vol. 91, No. 2, pp. 144-150.

Dally, J. W. and Riley, W. F., 1978 , “Experimental stress analysis.” New York: McGraw-Hill.

Finger, I. M., Castellon, P. and Elian, N. 2003 ,“The evolution of external and internal implant/abutment connections.” Pract Proc Aesth Dent, Vol. 8, No. 15, pp. 625-634.

Goodacre, C. J. *et al*., 2003, “Clinical complications with implants and implant prostheses.” J. Prosthet. Dent., Vol. 90, No. 2, pp. 121-132.

Hansson, S., 2003 “A conical implant-abutment interface at the level of the marginal bone improve the distribution of stress in the supporting bone. An axisymmetric finite element analysis.” Clin Oral Impl Res, Vol. 3, No. 14, pp. 286-293.

Haraldson, T., 1980 “A photoelastic study of some biomechanical factors affecting the anchorage of osseointegrated implants in the jaw.” Scandinavian Journal of Plastic Reconstruction Surgery, Vol. 14, No. 3, pp. 209-214.

Hoshaw, S. J.; Brunski, J. B. and Cochran, G. V. B., 1994, “Mechanical loading of Brånemark implants affects interfacial bone modeling and remodeling.” Int. J. Oral Maxillofac. Implants, Vol. 9, No. 3, pp.354-360.

Iplikçioglu, H., Akça, K., Çehreli, M. and Sahin, S., 2003 “Comparison of non-linear finite element stress analysis with in vitro strain gauge measurements on a morse taper implant.” Int J Oral Maxillofac Impl, Vol. 18, No. 2, pp. 258-265.

Kitamura E. *et al*., 2004, “Biomechanical aspects of marginal bone resorption around osseointegrated implants: considerations based on a three-dimensional finite element analysis.” Clin. Oral Impl. Res., Vol. 15, No. 4, pp. 401-412.

Norton, M. R., 1997, “An in vitro evaluation of the strength of an internal conical interface compared to a butt joint interface in implant design.” Clin Oral Impl Res, Vol 8, No. 4, pp. 290-298.

Taylor T. D., 2003, “The changing face of implant dentistry.” Int J Oral Maxillofac Implants, Vol. 18, pp., No. 6, 793.

Taylor, T. D. and Agar, J. R., 2002, “Twenty years of progress in implant prosthodontics.” J Prosth Dent, Vol. 88, No. 6, pp. 793.

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