# SYSTEMS ANALYSIS OF DENTURE FIXED WITH FOUR IMPLANTS

**Luiz Carlos Gonçalves Pennafort Jr., luizpennafortjr@yahoo.com.br**
**Silvestre Carvalho de Oliveira Jr., silvestre_carvalho@hotmail.com**
**Enio Pontes de Deus, epontes@ufc.br**
Failure Analysis and Materials Testing Laboratory, Federal University of Ceara, Brazil.

***Abstract.*** *The present study aimed at obtaining comparative elements among the guided systems of fixed complete denture with four osseointegrated implants with immediate loading, considering the importance of understanding the implant project as a process where biomaterials and biomechanics are assessed. The finite element method was used to analyze the stress concentrations in the whole implant-supported system, associated to the variation of the material of the prosthetic bar among the nickel-chromium, cobalt-chromium and Ti-6Al-4V alloys. Metallographic tests of the Ni-Cr and Co-Cr alloys, were made with the objective of identifying the micro-structure and consequently evaluate its influence in the mechanical behavior of the system. Two systems were analyzed, one with cantilever and another without it, but with tilted implants, submitted to a vertical load of 756N. The study of the alloys indicates the Co-Cr alloy as a material comparable to the other ones, regarding the mechanical behavior.*

***Keywords****: Dental Prostheses Supported, Dental implantations, Biomechanics, Finite Element Method.*

## 1. INTRODUCTION

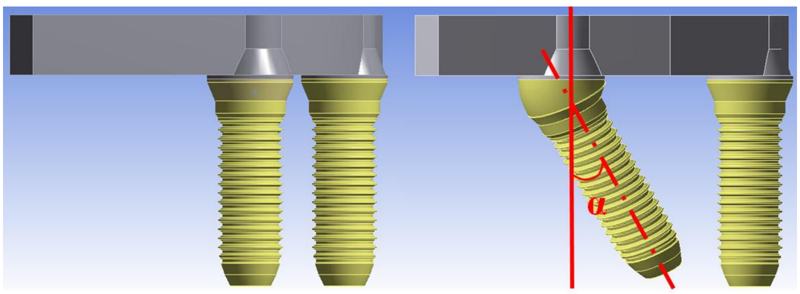
The treatment of dental problems has been following the human being throughout his life. Also and more important, there are ancient manuscripts which describe the methods of dental treatment dating back to 3000 *BC*. In addition, its main interest is the replacement of the missing teeth (Moore, 2003).

Through many years with the development of the dentistry, there has also been a necessity of formation of new materials. In particular, researchers have evaluated their mechanical and physical properties, which exert considerable influence on its structural stress distributions (Geng et al., 2008). Generally, these properties are highly dependent on its microstructure, which is determined by the quantity, size, shape and distribution of phases and crystal defects (Padilha, 2000). In addition, they are selected so as to use in implants. Not only the chosen materials are biocompatibles, but they will also have mechanical properties compared to the biomaterial being replaced, whatever the bone (Callister, 2002). Nevertheless, there is also a great number of metallic alloys which are used for dental reconstruction. They are divided into two main groups, which they include elements have such as *Au, Pt, Ag, Pd* and so-called “other alloys” of *Co-Cr, Ni-Cr, Ti* and stainless steel. Generally, the last group has mechanical properties and wear strength highly superior to those of noble metal alloys (Vilar, 2008).

The expansion of dentistry has also arised new areas, such as Implant dentistry.  As a result of it, countless dental systems are also implemented. Moreover, these systems are based on the principles of the osseointegration, which promotes direct anchorage. Particularly, this anchorage is capable of withstanding the occlusion forces originated during mastication (Dias, 2001).

Recently, the prosthodontic systems has been based on the immediate loading, by means of using various biocompatible materials. Nonetheless, there are a lot of controversy among professionals over its biomechanical behavior. Relating to it, there are some doubts about the level of stress generated and the deformation of the prosthetic components. Mainly, due to chewing loading and during the swallowing (Naconecy, 2006). As it means, there are some regions of the implant which have high level of stress. Furthermore, it can cause serious structural damage in the system (Reis et al., 2002).

The main objective of this work is to compare two immediate loading implant systems by using Finite Element Analysis (FEA). The first is the Brånemark protocol implant-supported fixed denture and the second one is considered an implant-supported inclined fixed denture, Fig. 1. In addition, it is also compared three different alloys, such as *Co-Cr, Ni-Cr* and *Ti-6Al-4V*.




a) *A* – Straight implants  b) *B* - Inclined implants ($\alpha$ = 30°)
Figure 1. Side view of the cantilever extension

## 2. MATERIALS AND METHODS

### 2.1 Geometry

The first stage consists of designing the main components of the dental implants, which are used for rehabilitation of the edentulous mandibles. Furthermore, they follow the philosophy of two guided systems of dental prostheses with immediate loading. Figure 2 shows the configuration of the systems.

a) *A* - four implants b) *B* - four implants, with the back implants angulated.

Figure 2. Configuration of dental prostheses systems

The dimensional parameters of the whole prosthetic (implant, straight and angulated abutments (30°), abutment screw, screw and cylinder prosthetic) were based on implant type Brånemark System ® MkIII - 3.75 x13 mm, while the bar prosthetic is similar to the curvature of the arc of a human mandible for training in integrated implants (ETH 0301-10 Nobel Biocare, Gothenburg, Sweden). Figure 3 shows the main geometric parameters of the prosthetic bar, where the variable *w* represents the width, *t* (thickness), *R* (radius of curvature), *d* (distance between the abutments), prosthetic bar used in the analysis. However, it worths mentioning that $b = 1.5\ a$ (Telles and Coelho, 2006).

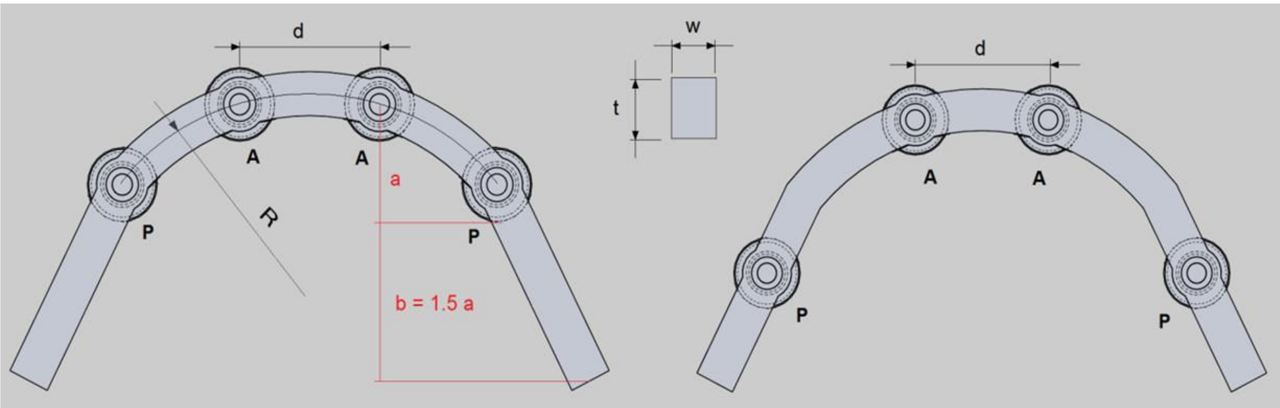



Figure 3. Geometric parameters of the prosthetic bar of dental prostheses systems *A* and *B*.

The values of the geometric parameters above considered in this study are (Naconecy, 2006):
$w = 4$ mm
$t = 3$ mm
$R = 17.65$ mm
$d = 10$ mm

### 2.2 Material

Initially, it was verified some standard procedures so as to prepare the alloys in order to evaluate its characterization, ASTM E 3 – 01. The specimens were ground in automatic grinder following the sequence of grit sizes of 220, 440, 600 and 1200 micrometers. After that, they were polished by using both six microns and one micron diamond paste then, the specimens of Ni-Cr and Co-Cr were attacked with chemical solutions, according to ASTM E 407-99, Tab. 1. The attacks of the specimens were held in proper place, due to the exhalation of acid gases involved.

Table 1. Chemical solutions and procedures to be used in etching metals for microscopic examination.

| Metal | Reagent Chemical | Procedure |
|---|---|---|
| Ni-Cr | 20 mL $HNO_3$<br>80 mL HCl | Immerse 5 –30 s. |
| Co-Cr | 5 mL $H_2O_2$ (30%)<br>100 mL HCl | Use hood. Mix fresh. Immerse polished face up for few seconds. |

The main elastic properties of the alloys are showed in Tab. 2.

Table 2. Mechanical properties

| Material | Elongation (%) | Yield Strength (MPa) | Tensile Strength (MPa) | Modulus of elasticity (GPa) | Poisson's ratio |
|---|---|---|---|---|---|
| Ni-Cr | 3(1) | 258(1) | 306(1) | 188(2) | 0,33(2) |
| Co-Cr | 3,4(1) | 663(1) | 711(1) | 210(2) | 0,33(2) |
| Ti-6Al-4V(3) | 14 | 924 | 993 | 114 | 0,33 |

(1) : values provided by manufacturers - Talladium do Brasil
(2) : (Geng et al., 2008)
(3) : (Knittel and Wu, 1998)

**2.3 Numerical Analysis**

A numerical model based on the finite element method was developed within the framework of an international code, so as to simulate the behavior of guided systems of dental prostheses with immediate loading. Three-dimensional quadratic tetrahedral elements were used to model the assembly. The material was considered isotropic, linearly elastic (Falcón-Antenucci et al., 2008).

After defining the mechanical properties of the materials involved, the process of generation of finite element meshes is evaluated. The meshes of the models used in this study were of 115,636 elements for the system A and 108,350 elements for the system B. They were defined, after checking the convergence of the critical value of the prosthetic bar ($S_n$). It is judged, when the convergence changes in value as the mesh refinement proceeds decrease by more than 10% (Sinclair and Beisheim, 2008)

Then the critical results were extrapolated to the asymptotic result by "Richardson's Extrapolation", Fig. 4. However, this procedure is the simplest way to get a better estimate from three (or more) sets of results on hand, and not a theoretically valid method to obtain the asymptotic value. Furthermore, such extrapolation and the estimated value are valid only locally and for the specific critical value plotted (Geng et al., 2008).

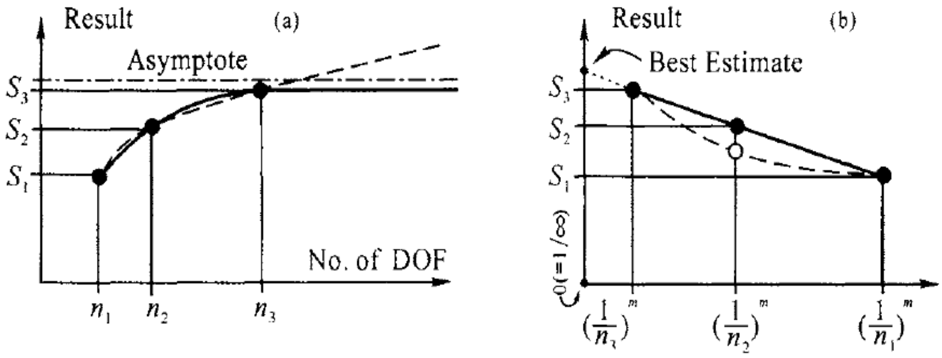



Figure 4. Results from Three Meshes for (a) Linear Plot, and (b) Exponential Plot

During the numerical analysis the implants were considered as cantilevers (perfect osseointegration). Although the implants whole integrated with the bone as not clinically considered as a real situation, it can be take into consideration as a first approximation. It provides a good indication of the material behavior and stress distributions (Pacheco, 2008). It was applied a static vertical force of 756 N, which is refer to a higher sustained average masticating force (Souza, 2007). It is distributed along the superior face of the structure, Fig. 5.

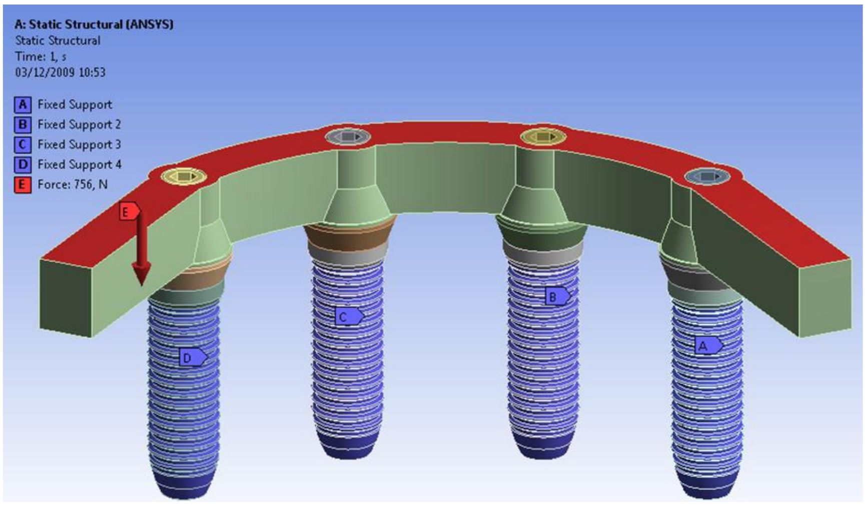



Figure 5. Loading distribution of the prothetic systems

## 3 RESULTS AND DISCUSSION

### 3.1 Micrographs of Nickel-Chromium and Cobalt-Chromium alloys

Figure 6 shows an image of a solid solution of chrome (dendritic shape) in nickel, where the interdendritic region can have metallic carbide and other intermetallics (Sá, 2006).

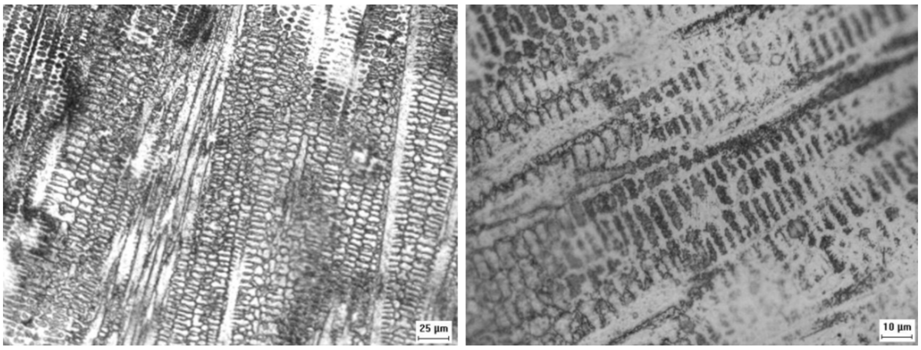



Figure 6. Microstructure of the Ni-Cr (magnified 200 and 500 times).

The micrographs are obtained by means of a Cobaltum-chrome alloy, Figure 7. It shows that the micrographs aspects are similar to the *Ni-Cr* alloy, where it is seen carbides in elongating shape (Yamakami et al., 2006), thereby providing its fragility and also reducing the elongation of the alloy (Asgar and Peyton, 1961).

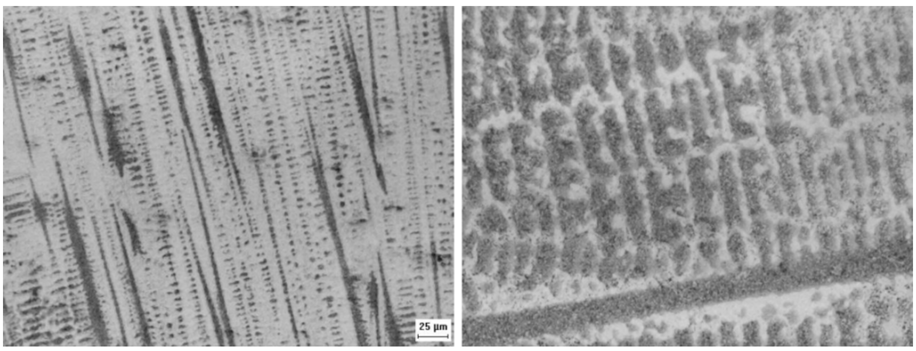



Figure 7. Microstructure of the Co-Cr (magnified of 200 and 500 times).

It worths highlighting that the dendrites always appear when a metal is melting. After that, this metal can be transformed into a granular strengthen structure by means of a thermal treatment (Pedrazini and Wassall, 2009).

### 3.2 Evaluation general of the implant systems

In this work, attention is drawn by a global comparison between two dentistry prosthetic systems and also the metallic alloys analyzed. However, the regions of concentration stresses are more interested in terms of qualitative than quantitative. Nonetheless, it was used Richardson's Extrapolation so as to obtain trustworthy results in a prosthetic bar (principal structure). Figures 8 and 9 show the correlation of *n* elements compound models graphically due to its critical stress values (*S*).

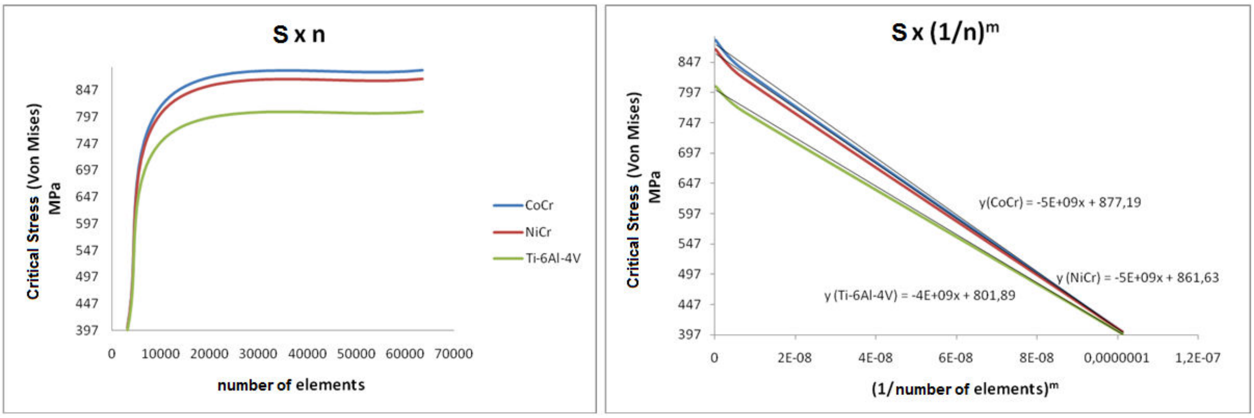



Figure 8. Linear and exponential critical results of the prosthetic bar (system A).

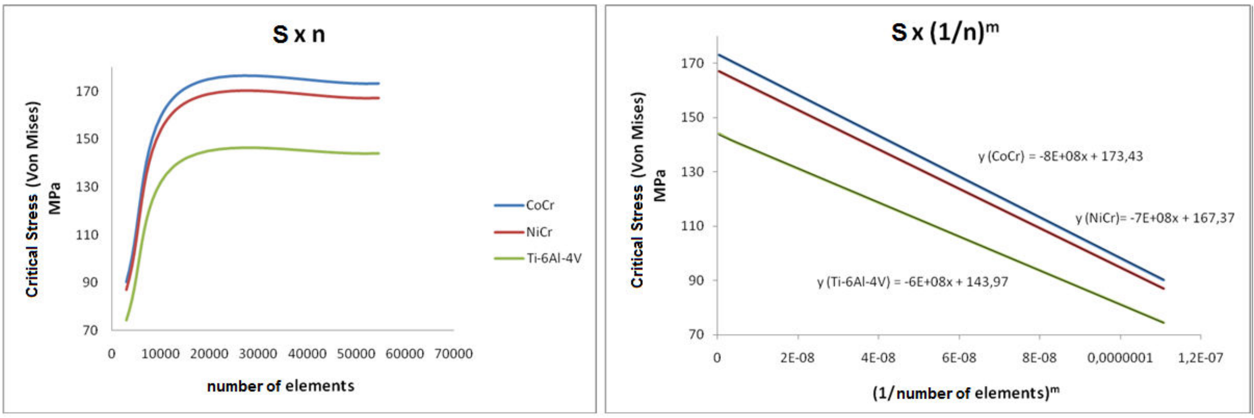



Figure 9. Linear and exponential critical results of the prosthetic bar (system B)

The qualitative analysis was evaluated by means of observation of the graphical images, Figures 10, 11 and 12. It was also observed the values of Von Mises Stresses and total strains of the models, Table 3. It is noteworthy the improvement of stress distributions on the prosthetic bar (system B), thereby reducing 81% and 90% of the level of stress and total strain, respectively. Moreover, the bending is reduced because the cantilever length is also reduced.

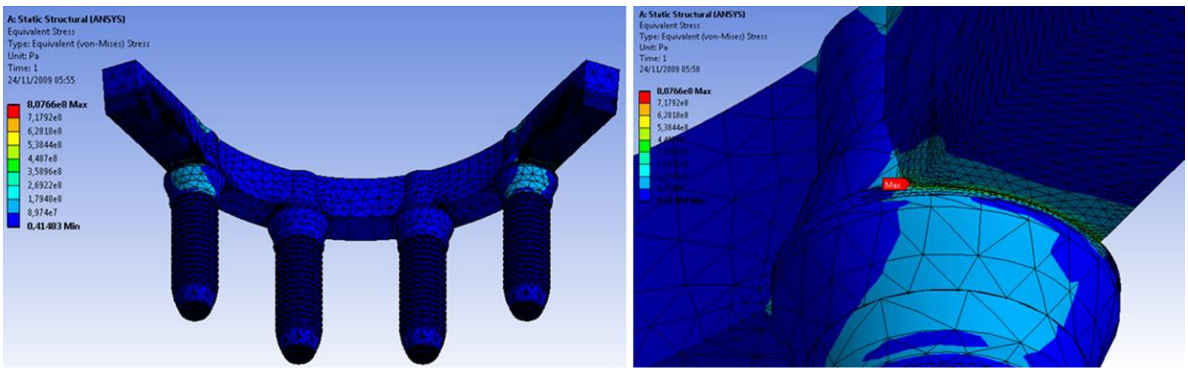



Figure 10. Equivalent (von Mises) Stress - system A

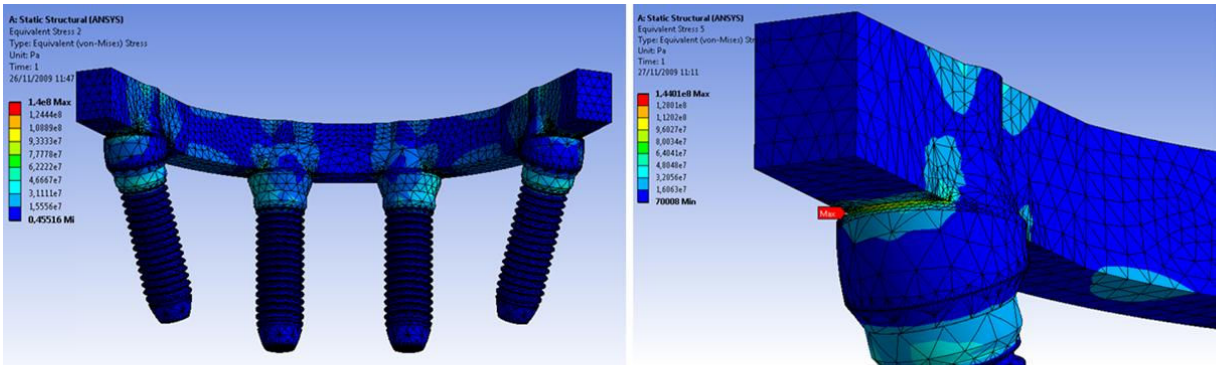


Figure 11. Equivalent (von Mises) Stress - system B

Table 3. Computational data from the study of prosthetic bars

| Implant System | Material | Total Deformation (mm) | Equivalent (von Mises) Stress (MPa)(1) | Maximum Force Resultant Axial direction of the abutment (N) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Abutment(2) | | | |
| | | | | P | A | A | P |
| A | Ni-Cr | 0,0371 | 868,33 / 124,95 | 317 | 61 | 61 | 317 |
| | Co-Cr | 0,0346 | 884,20 / 123,58 | 318 | 60 | 60 | 318 |
| | Ti-6Al-4V | 0,0516 | 807,66 / 130,87 | 308 | 70 | 70 | 308 |
| B | Ni-Cr | 0,0039 | 167,16 / 28,69 | 216 | 162 | 162 | 216 |
| | Co-Cr | 0,0037 | 173,18 / 28,65 | 216 | 162 | 162 | 216 |
| | Ti-6Al-4V | 0,0052 | 144,01 / 28,91 | 215 | 163 | 163 | 215 |

(1) : Maximum Stresses: prosthetic bars / interface abutment-implant
(2) : P - posterior and A - anterior

The analyses also showed an average reduction loading in posterior abutments of 31% of the system B in relation to the system A. Also and more important, this result is closer to the value of 28%, which was found in similar study. Herein, the results were obtained by extensometers (acquisition data) (Naconecy, 2006). Furthermore, this reduction is due to the posterior implants inclination. In addition, this inclination allows a better bending and stress distributions. This situation is observed when it is compared the total deformations of both systems, Figure 12.

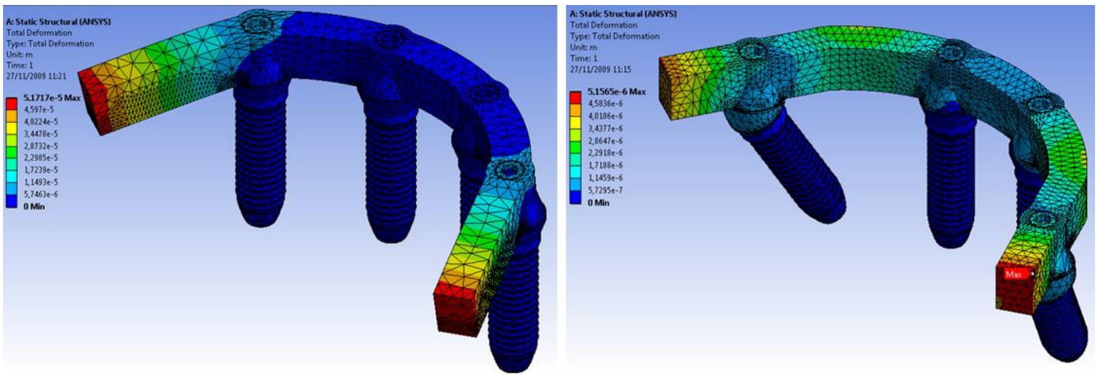


Figure 12. Total deformation - systems *A* and *B*.

In relation to the level of stress of the materials, it was not observed any significative difference between *Ni-Cr and Co-Cr* alloys. Nevertheless, the *Ti-6Al-4V* alloy has shown a better stress distribution along the prosthetic bar and higher level of deformations (both systems), due to its Elasticity Modulus value (Pennafort Jr, 2009). In addition, when the material used in the prosthetic bar presents low Elasticity Modulus, it can cause higher deformations and also a higher consumption of Deformation Energy. Owing to it, there is a high concentration stress in the interface implant/bone at the side of the load applied, Table 3 (Benzing et al., 1995). Several authors recommend high elasticity modulus of the prostheses so as to avoid deflection of the structural prosthetic and stress concentrations in the retaining screw (Geng et al., 2008).

In these models, it was not possible to consider the effect of the loading due to wheel fixing bolt tightening torque of prosthetic bar. By virtue of it, the contact region between the abutment and abutment screw was more refined. Moreover, there was a highly increase of the mesh and also of the computational effort. Nonetheless, the results were not affected, because this is a qualitative study.

**3.3 Behavioral analysis of prosthetic systems according to the implant systems.**

The finite element results of the prosthetics systems were based on the Maximum Principal Stress ($\sigma_1$), Minimum Principal Stress ($\sigma_3$) and Von Mises Stress ($\sigma_{eq}$) around the implant, close to the interface implant/bone (cervical region), Table 4. Based on the results, the inclination can cause a considerably increase of the principal stress. In addition, it is also observed an increase of approximately 15% of the Von Mises Stress. It worths mentioning that compressive stresses are five times higher in the cervical region of the inclined implant in relation to the straight implant (Canay et al., 1996).

Table 4. Principal stresses in the cervical region of the implant (*Ti-6Al-4V)*

| Systems | Loading (N) | whole prosthetic | Principal Stresses (MPa) implant (Cervical Region) | | |
|---|---|---|---|---|---|
| | | | $\sigma_1$ | $\sigma_3$ | $\sigma_{eq}$ |
| A | 308 | Straight | -2,69 | -40,11 | 33,20 |
| B | 215 | Inclined | 34,13 | 15,23 | 51,44 |

However, it is important to mention that the results must be analyzed with caution. Mainly, because of the amount of variation of the individual biological characteristics. For that reason, it was limited the complete extrapolation of the results for different clinical situations (Blatt et al., 2006).

**4. CONCLUSIONS**

This work presented a comparative study among the guided systems of fixed complete denture with 4 osseointegrated implants with immediate loading through FEA. The system B showed to be more appropriate in relation to the integrity of the prosthetic bar, thereby reducing its level of stress. Nonetheless, the interface implant/bone stress is highly superior and it can cause serious damage to the patient such as bone remodelation, micro bone fractures, marginal bone loss, prosthetic complications and even causing the loss of implants (Blatt et al., 2006).

In relation to the material used, it is clear that *Co-Cr* alloy showed better behavior mechanical compared to the other materials. Owing to it, this material is highly favorable in terms of using in Implant Dentistry area. Nevertheless, the micrograph showed a dendritic shape of the *Ni-Cr* and *Co-Cr*, alloys, thereby contributing to its fragility.

**5. REFERENCES**

Moore, D.E., 2003, “History of tooth replacement and dental implants and current status of dental implants”. A research paper. Combat Health Support Seminar, U. S. Army Command and General Staff College, Kansas: Fort Leavenworth,.

Geng, J., Yan, W. and Xu, W., 2008, “Application of the Finite Element Method in Implant Dentistry” – Zhejiang University Press, Hangzhou and Springer – Verlag GmbH Berlin Heidelberg, China.

Padilha, A.F., 2000, “Materiais de engenharia microestrutura e propriedades”. Hemus Livraria, Distribuidora e Editora S.A. Curitiba – PR, 343p.

Callister, Jr. W.D., 2002, “Materials Science and Engineerin g: An Introdution”. John Willey & Sons, Inc. 2000. Tradução de SOARES, S. M. S., 5º edição, 589p.

Vilar, C.D., 2008, “Influência do número de refundições da liga Ni-Cr-Mo-Ti sobre as propriedades de próteses metalocerâmicas”. Tese (Doutorado em Ciência e Engenharia de Materiais) – Universidade Federal do Rio Grande do Norte. RN, 139p.

Dias, R.P., 2001, “Precisão de adaptação e ajuste horizontal de abutments unitários em sistemas de implantes com hexágono externo”. Dissertação (Mestrado) - Faculdade de Odontologia de Bauru, Universidade de São Paulo, Bauru, SP, 204p.

Naconecy, M.M., 2006, “Força e momento Fletor em pilares de prótese tipo Protocolo Bränemark em função da inclinação dos implantes distais e do número de pilares”. Tese de D.Sc., Faculdade de Odontologia, Pontífica Universidade Católica do Rio Grande do Sul, Porto Alegre, RS.

Reis, T.C.A., Elias, C.N and Gouvêia, J.P., 2002, "Análise de tensões elásticas em implantes dentários pelo Método de Elementos Finitos", Revista Matéria, v. 07, n. 2.

Telles, D. and Coelho, A.B., 2006, "Próteses SobreImplantes.com". Rio de Janeiro: SobreImplantes.com, 18 sep 2007. < http://www.sobreimplantes.com/materialAcademico.asp#livro>.

Knittel, D. and Wu, J.B.C., 1998, Titanium and its alloys, In: "Kutz, M., Mechanical Engineer's Handbook". 2nd Ed. John Wiley & Sons, Inc. cap. 6, p. 1-18.

Falcón-Antenucci et al., 2008, "Avaliação das tensões na interface implante/coroa". Rev. Cir. Traumatol. Buco-Maxilo-fac, Camaragibe v.08, n.3, p. 49 - 56.

Sinclair, G. and Beisheim, J., 2008, "Alternative convergence-divergence checks for stresses from FEA", In: 2008 International ANSYS Conference. Pittsburgh Pennsylvania, U.S.A.

Pacheco, N.D., 2008, "Distribuição de tensões em implantes dentários inclinados empregando o método dos elementos finitos". Dissertação de M.Sc., Instituto Militar de Engenharia, Rio de Janeiro, RJ, Brasil.

Souza, C.F., 2007, "Resistência à fratura de subestruturas para próteses parciais fixas posteriores de zircônia densa sob testes de fadiga cíclica". Dissertação de M.Sc., COPPE/UFRJ, Rio de Janeiro, RJ, Brasil.

Sá, J.C., 2006, "Efeito das variáveis laboratoriais protéticas na adesão da porcelana com ligas de níquel-cromo".. Dissertação (Mestrado em Ciência e Engenharia de Materiais) – Centro de Ciências Exatas e da Terra, Universidade Federal do Rio Grande do Norte. 102p.

Yamakami, W.J. et al., 2006, "Influência do percentual de vazios nas propriedades mecânicas de ligas odontológicas fundidas a base de Co-Cr-Mo". 17º CBECIMat – Congresso Brasileiro de Engenharia e Ciência dos Materiais. Foz do Iguaçu, PR. p.6804-15.

Asgar, K. and Peyton, F.A., 1961, "Effect of casting conditions on some mechanical properties of cobalt-base alloys". Journal Dentistry Research, v. 40, n. 1, p. 73-86.

Pedrazini, M.C. and Wassall, T., 2009, "Falhas de fundição nas infraestruturas de próteses ferulizadas sobre implantes: ensaio in vitro". Revista Gaúcha de Odontologia, v.57, n.2, p. 165-172 Porto Alegre.

Pennafort Jr., L.C.G., 2009, "Análise de sistemas de implantes dentários em mandíbulas edêntulas com aplicação de carregamento imediato". 97p. Dissertação (Mestrado em Ciência e Engenharia de Materiais) – Universidade Federal do Ceará, Fortaleza, CE, Brasil.

Benzing, U.R., Gall, H. and Weber, H., 1995, "Biomechanical aspects of two different implant-prosthetic concepts for edentulous maxillae". Int. J. oral maxillofac. Implants, v. 10, n. 2, p. 188-98.

Canay, S. et al., 1996 "Comparison of stress distribution around vertical and angled implants with finite element analysis". Quintessence Int., v. 27, n. 9, p. 591-598.

Blatt, M., Butignon, L.E. and Bonachela, W.C. 2006, "Análise de elementos finite aplicados a implantodontia – uma nova realidade do virtual para o real." Innovations Implant Journal – v. 01, n. 02, p. 53-62.

## 5. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.