EXPERIMENTAL ANALYSIS ON THE FASTENING OF COMPONENTES OF AN IMPLANT-SUPPORTED DENTAL PROSTHESIS

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Abstract. *Researches involving different areas of knowledge have improved for years the development of techniques for treatment and the recovery of patients. In this sense, mechanics and medicine have played a great role in the study of new equipments and materials that can bring back the movement and the reconstruction of parts of the body, as well as in the understanding of the human tissues. In this direction, this research considers the behavior of dental prostheses and, more specifically, of their components. The dental prosthesis is constantly under forces due to the chewing strength, which produces stress on its structure. But these structures already have internal assembling stresses produced by the process of fixing the implants to the bone tissue and fastening of prosthesis components. These internal stresses can damage the prosthesis structure. If this structure has high values (stresses) when requested for chewing, they can break or hurt the bones tissues. So, there is a sum of forces, that is, the assembling force and the chewing force. For this analysis, an experimental apparatus was set up using strain-gauges to capture the deformation on the abutments. The abutment is the prosthesis component that connects the implant to the prosthesis structure, where artificial teeth are held. The analysis took place on the fastening of the abutment. It can be noticed that each abutment behaves differently and the fastening by itself produces significant deformations on the abutment. These studies are part of an analysis package about the forces on the prosthesis components. They have the purpose of improving the project of the prosthesis and to reduce the incidence of breakings and injuries to the patients.*

Keywords*: bioengineering, dental prosthesis, stress analysis, strain- gauges, resistance of materials.*

1. Introduction

Knowledge on the effects caused by the use of implants and prosthetic structure has increased significantly along the years. Many researches have been developed to confirm the efficiency and durability of materials used in such prosthesis. Engineering, more specifically Mechanical Engineering, has contributed on the analysis of those structures, for their mechanisms are analogous to mechanical structures. Materials used in prosthesis are, in many instances, the same used in precision microscopy equipment, automobile parts, precision tools and a plethora of mechanical components. Because of this, the combination of medical a mechanical knowledge is imperative. Medicine has the role of identifying possible disturbances caused by the use of implants and Mechanics has the role of analyzing stress problems on a given structure according to the type of material. The combination of these two science fields is known as bioengineering or biomechanics.

The volume of implant-supported prosthesis has increased dramatically over the last years and so has increased the need for information. Unfortunately, these needs are the result of the losses occurred in wars. The Second World War was a laboratory for advances in prosthesis, for many soldiers returned from the battlefield with missing arms and legs and needed apparatus to facilitate reintegration to the society, not only with crutches and wheel chairs, but also with artificial arms and legs. Those mechanical limbs were not alike today's, having only a cosmetic function, incapable of making movements. They were used in comb ination with crutches to help maintain body balance.

Oral bioengineering only had its rise when esthetic standards began to be more important to the society. After the Second World War, facial and dental reconstructions were deficient. In many instances, patients that undergo implant surgeries presented sequellae and rejection to the materials used. The search for materials with adequate strength and techniques that did not cause injuries to live tissues became the focus of research. Research on equipment and surgical techniques and structural behavior of prosthesis were also developed.

Researches continue in the direction of making these techniques accessible to the entire population, since it is still too expensive to the majority of people.

Besides the study on the physical and structural behavior of dental prosthesis, it is important to underscore that the most significant results of those researches consist in the search for new methods and materials that can revolution dental treatment, providing the population an opportunity of living a healthier and esthetically more pleasant life.

Many authors have developed research on the field of Dentistry-related biomechanics. One of the first works was conducted by Skalak, on the stresses of osseointegrated dental implants, as well as the use of shock absorbing materials that could dampen the loads on bony tissue. Skalak stated that this kind of prosthesis has as critical factors the incidence and load transfer of mechanical stresses to the implants and from these to the surrounding bone. He stressed the importance of using materials capable of absorbing and better distribute load, like acrylic resin and artificial teeth. (Skalak, 1983)

Another important work was the one by Millington e Leung, which analyzed the fit between the prosthesis components. (Millington e Leung, 1992)

More recently the work done by Jacques also analyzed an implant-supported prosthesis regarding the distribution of forces among the prosthesis components when loaded. (Jacques, 2000)

Carlsson e Carlson stressed that there is no absolutely passive fit between the components since any screw fastening generates a certain amount of deformation. They suggested two types of measuring the degree of misfit, used in a clinical situation. (Carlsson e Carlson, 1994)

2. Strain-gauges

Strain-gauges are used in experimental analysis of stress and strain. It is based on the characteristic of the material that changes according to the electric resistance with deformation. Deformation of a material is, by definition, the variation of size along its length. It is represented by the Greek letter 'ε' and is not measurement. (Beer e Johnston, 1995), given that its mathematical equation is:

$$\varepsilon = \frac{\Delta L}{L} \tag{1}$$

being ΔL the variation of length and L the original length.

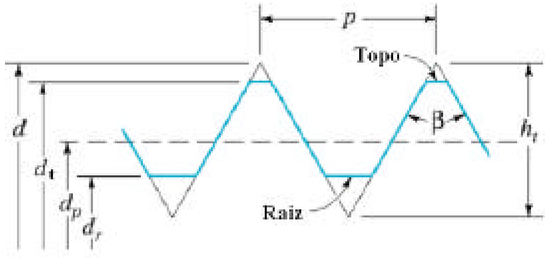
Regarding the type and geometry of the strain-gauges, they can be classified according to the precision required in the measurements, degree of protection with the environment and reliability of measurements in the medium and long term. (National Instruments, 1998)

Today the use of strain-gauges became imperative in the experimental analysis of structures, being extensively used in nautical, aviation, automobile, medical as well as other industries. Its large application is due to the reliability of its results, as well as to the easiness of utilization. Particularly in structures for dental prosthesis the use of such instruments is essential because the components are of milimetric size and there is limited room for large measuring tools.

3. Screw retained joints

Screws are machine elements that hold different parts that need to work or withstand loads together. It is the intent of this topic to review some general notions about the threads and screws, for the junction of the metallic elements of the prosthesis are hold together this way. Governing analytic equations of screws problems are of great importance for the comparison of the experimental results obtained here.

The fastener's threads are constitutes of following basic parts:



Being p pitch, d the diameter, d_t the top diameter, d_p the primitive diameter, d_r the root diameter, h_t the hight of the thread and β the angle of the thread.

Figure1. Screws threads

There are many types of threads, with different geometries and functions. Among the most used are the trapezoid and the square. A less common model in mechanics, but widely used in lamps, is the rounded profile thread. (Hamrock, 1999)

The pitch is an important factor for threads, for through it is possible to know what the advance of the screw will be. This advance can depend also on the number of entries, that is, the number of screw threads a screw has. As bigger the number of entries, the faster the advance will be.

The two types of crews, according to the angulation of the thread are the Milimetric thread (β = 60°), CGS System, and the Withiuort threads (β = 29°), English System.

$$T_r = W\left[\frac{d_p}{2}\left(\frac{\cos\theta_n \tan\alpha + \mu}{\cos\theta_n - \mu\tan\alpha}\right) + r_c\,\mu_c\right] \qquad (2)$$

This equation represents the calculation for comparison with the experimental data reported in sequence. (Hamrock, Jacobson e Schmid, 1999)

4. Methods and material

Strain-gauges: It consists of an electric resistor with a very thin layer of conductible material laid over an isolation material. Because of the size of the dental prosthetic components, the strain-gauge used is the KFG-02-120-C1-11 supply by Kiowa Electronic Instruments Co., Ltd. witch is one of the smallest in the market, with a precision of 10^{-6} of deformation.

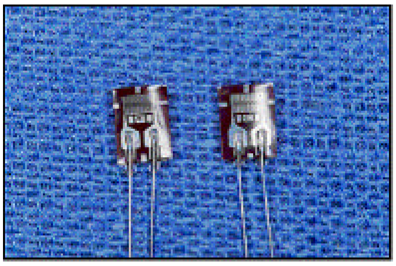


Figure 2. Strain-gauges

Acquisition Boards*:* For the measurements of strain-gauges variations of resistance, acquisition and interface boards for data transmission to the acquisition software were used. Those boards send an electric sign to the system obtaining a voltage to make communication with the computer.

Software LabView: Uses a graphic programming language, G language programming, to create diagrams. In this software the results are read and stored. (National Instruments, 1998)

Multimeter: Used to verify whether the strain-gauges are presenting the nominal resistance value given by the manufacturer;

Circuit Board: Used to making the connection between the acquisition wires and the strain-gauges, it has continuous copper bands;

Welder*:* Iron used to melt the weld;

Weld: Tin weld to connect the board and the wires;

Torquimeter: Development by Nobel Biocare Torque Controller, Gotenburg, Sweden, electronic equipment used to give a controlled torque to the screws;

Hand-held screwdrivers: Used before the final fastening with the torquimeter and for unscrewing;

Fixation table: Used to hold the assembly during tests. Consists of three mobile parts;

Master Model: Made of common steel (ABNT 1020/30). The master model replicates a human mandible. Contains five radial perforations for placement of the implants and 5 others, tangentially placed to hold the implants in place;

Implants (Replicas): 5 implant replicas were used to support the prosthetic apparatus. These replicas represent the implants fixed to the mandible bone. They have not the threads present in actual implants;

Abutments: Abutments are connecting elements between the implants and the prosthesis structure. Made of titanium, the abutment is composed by a 4mm high cylinder trespassed by a hollow screw that fixes it to the implant. The hollow in the screw head is threaded to receive another screw that holds the prosthesis into place;

Metallic structure: Since the artificial teeth are made of acrylic resin, a metallic structure is needed to hold the teeth and to resist to the chewing forces. Because of anatomic limitations, it is difficult to place implants in the posterior region of the mouth. Therefore, the structure is supported on its anterior segment by the implants and projects posterior with cantilever arms to hold teeth in the back of the mouth. The structure takes the load that is transferred by the artificial teeth. This assembly, artificial teeth plus metallic structure, is fixed to the abutments by means of a small screw. This research did not study this component, only the abutments fastening;

Figure 3. Components of prosthesis to be analyzed

All the components are made out of titanium. Titanium properties like resistance to corrosion and tolerance to live tissues make this material the most used for medical purposes.

Table 1. Characteristics of materials used in the experiment

Alloy	Content	Elastic Modulus (GPa)	Specific weight (g/cm^3)
Titanium Alloy	Ti – 72%	110	4,54

Compared to steel, titanium is lighter and more elastic, what facilitates the transmission of loads and makes it more comfortable to the patients. Others materials can be mention, for example the alloy of CoCr used in many researches. (Chao, 1988 and Hulterström, 1991)

4.1. General methods

The test structure was fixed to a universal testing machine by the fixation table. This table allows a certain amount of movement so that the load applicator can be positioned. The circuit plate must be pois oned on the fixation table and be permitted to move together with the master model. The circuit plate must be cut to allow the assembly of the prosthesis components. Implant replicas (13 CNB) are positioned on the master model so that their heads were flat with the surface. Since these components are replicas of the actual implants, they do not have the threads responsible for fixation to the bone. Because of this, the implant replicas are fixed by allen screws laterally to the master model.

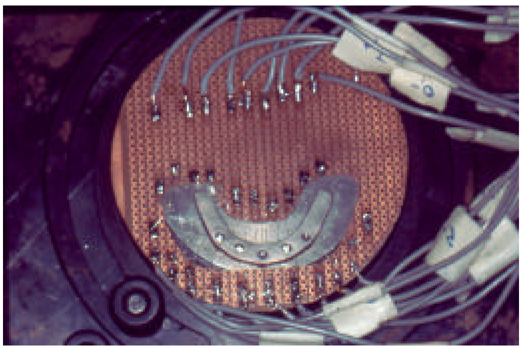


Figure 4. Experimental assembly

Although the previous picture shows the metallic structure screwed to the abutments, this study is focused only on the deformation of the abutments resultant of the fastening of the screws.

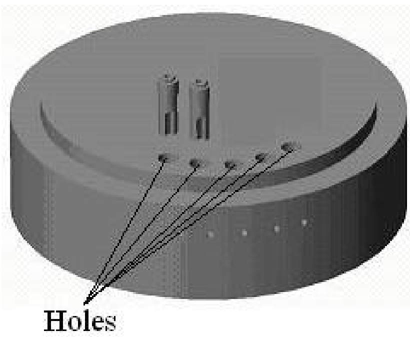


Figure 5. Fixation holes of the imp lant replicas

Onto the implant replicas, abutments (09 CNB-B) are screwed. As presented on figure 3, the abutments consist of two parts, the cylinder and the screw. The abutment screw also presents a small rubber ring to better seal the inner part of the implant from the oral environment. A 20Ncm torque is applied to the abutment screw by means of an electronic torque controller (Goll, 1991). In figure 3, it can be noticed that there is a hexagonal attachment on the bottom inner part of the abutment that connects to the hexagonal head of the implant. This hexagon avoids rotation of the abutment cylinder during screw fastening, what could damage the strain-gauges wires.

The fixation of the strain-gauges to the abutments is done before assembling to the implant replicas. The surface is cleaned with alcohol to ensure a perfect fixation of the strain-gauges (Tachibana). The surface must be cleaned in only one direction using a dry cloth, cotton tips or sponge; contaminants must be dragged out of the mounting area; the cleaning solution must be let dry on the surface. All these procedures being observed, the fixation of the strain-gauges is performed with special cyanoaclrylate glue provided by Kyowa.

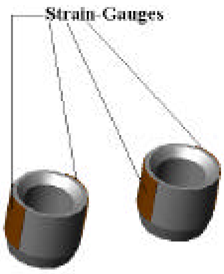


Figure 6. Fixation of strain-gauges

The arrangement of the strain-gauges on the abutments is done according to the direction of assembling of the prosthesis, that is, according to the curvature of the mandible, for they must be positioned in a way that, when load is applied, the strain-gauges can capture the deformation if the abutments in the same direction of the load.

After the strain-gauges are fixed they must be connected to the circuit plate. This connection is done with tin weld melted by an iron welder. The strain-gauge wire is welded to the circuit plate tensionless and with no contact with any surface whatsoever, for this contact can bring variations to the measure. The wire is welded to a copper band chosen to ensure that the specifications above be ensured.

On the other end of the copper band, the copper wires that connect to the acquisition plate are welded. These wires must be welded in the same manner of the strain-gauges wires, identifying the channel they are connected to. (Capuano, 1998)

4.2 Screw fastening

The abutment screw is fastening with a hand-held screw driver until some resistance is felt. Then, the acquisition plate is turned on and a 20Ncm torque is applied with the electronic torque controller. Time is given until the readings stabilize with final deformation and data are recorded. The same procedure is performed with the other abutments, one by one. At the end of the cycle the screws are released and a new cycle begins. The experiment is repeated five times to ensure the results are reliable.

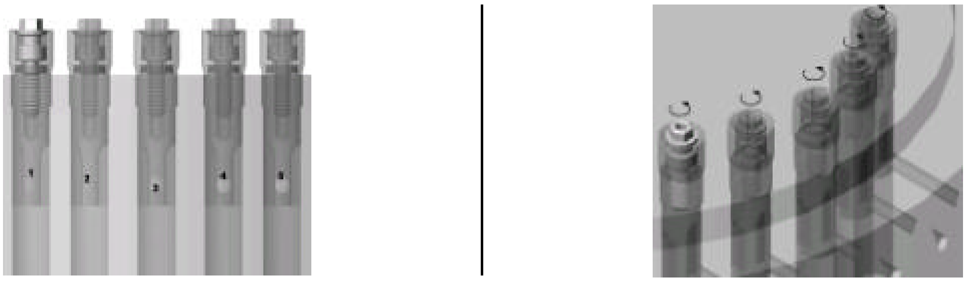


Figure 7. Details and fastening of the components

5. Results

The results can be divided in two parts: analytical and experimental. In the analytical part, calculations related to the fastening of the abutment screws and the deformations of the abutments are presented. In the experimental part, the data obtained in the laboratory are presented and a statistical comparison between them and the analytical data is done.

5.1. Analytic results

For this calculation, equations 1 and 2 and the basic equations of technical theory were used. Initial data of the screws are:

$$d_p = d - 0.649519 \cdot p = 2 - 0.649519 \cdot 0.4 \Rightarrow d_p = 1.74mm \tag{3}$$

$$\alpha = tg^{-1}\left(\frac{1}{\pi d_p}\right) = tg^{-1}\left(\frac{1}{\pi \cdot 1.74}\right) \Rightarrow \alpha = 10.37^\circ \tag{4}$$

$$\beta = 60^\circ \quad ; \quad \theta_n = tg^{-1}\left(\cos\alpha \cdot tg\left(\frac{\beta}{2}\right)\right) = tg^{-1}\left(\cos 10.37^\circ \cdot tg\left(\frac{60^\circ}{2}\right)\right) \Rightarrow \theta_n = 29.6^\circ \tag{5}$$

$\mu_c = 0.25$ (titanium with titanium) ; $r_c = 0.48$ mm ; $T = 200$ Nmm

The load applied to the screw is given by:

$$W = \frac{T}{\left[\frac{\left(\frac{d_p}{2}\right)\left[(\cos\theta_n \cdot tg\alpha) + \mu\right]}{\cos\theta_n - \mu \cdot tg\alpha} + r_c \cdot \mu_c\right]} = \frac{200}{\left[\frac{\left(\frac{1.74}{2}\right)\left[(\cos 29.6 \cdot tg 10.37) + \mu\right]}{\cos 29.6 - 0.25 \cdot tg 10.37} + 0.48 \cdot 0.25\right]} \Rightarrow W = 362.3N \tag{6}$$

The load W is evenly distributed along the bottom surface of the abutment (P). P is given by:

$$P = \frac{W}{A_{fa}} = \frac{362.3}{0.95} \Rightarrow P = 381.4N/mm^2 \tag{7}$$

Since the bottom ring of the abutment, that takes the load P, works like a fixed beam on the walls of the abutment, for at the beginning of the assembly this ring is not seated on anything, it deforms forcing the walls inwards, causing compression. Compression present negative values. The following figure represents the effects of the screw fastening on the abutment.

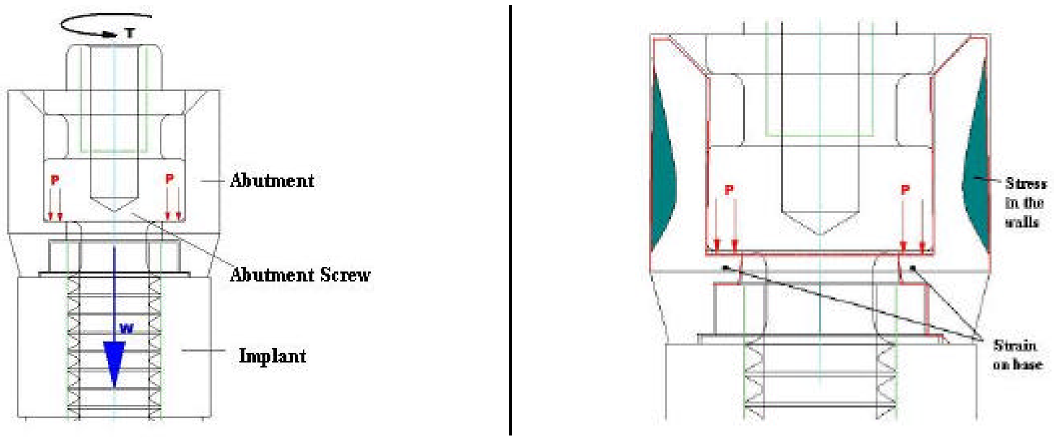


Figure 8. Effect of the abutment screw fastening

Deformations on the side walls of the abutment cannot be calculated by the technical theory formulations or resistance of the materials. Only softwares with numeric methods can get those results. Therefore, this section intends to present what happens in the structure of the prosthesis and how the deformations behave, with no values but with the dynamic of the components.

5.2. Experimental results

As already mentioned, strain-gauges were fixed to the abutments for the tests. Each abutment was connected to two strain-gauges, one on each side. The wires that connect the strain-gauges to the acquisition board were marked to facilitate the organization of the results. For instance, abutment number 1 had two strain-gauges connected to channels 0 and 1; abutment number 2 had its strain-gauges connected to channels 2 and 3 and so on, until abutment number 4. The acquisition board has enough room for connection of eight channels. For this reason, abutment number 5 was tested after the other four and the channels were named 0'and 1'.

Table 2. Identifying the strain-gauges

Abutment	Position	Channel
1	Left Right	0 1
2	Left Right	2 3
3	Left Right	4 5
4	Left Right	6 7
5	Left Right	0' 1'

Following are presented the means of deformation, where the heterogeneity of the results can be noticed. The results on both sides of a single abutment are rather uniform, though. Conclusions can be drawn after applying ANOVA to these results.

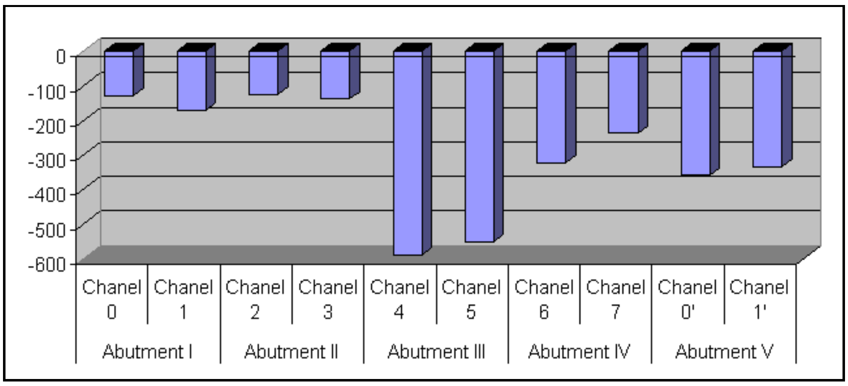


Figure 9. Final deformation results (in $\mu\varepsilon$)

It can be noticed by ANOVA (Costa Neto, 1995) that some of the results are not used for the calculation of mean deformation and the significance of the results can vary substantially. By the same analysis, now among abutments, significance can be noticed between some values of a given abutment. This is not uniform and therefore data must be analyzed for each channel individually and not divided by abutments right/left side.

Considerable values of deformation are presented in this study, given the tiny dimensions of the components. Therefore, it can be inferred the magnitude of stresses that the bony tissue is subjected to, not only because of chewing, but also because of the tensions present at the assembly of the prosthesis. If there is accumulation of tensions during chewing, the prosthesis can be in the plastic range of deformation resulting in damage to the bone.

6. Conclusion

Although this study concentrates in the deformations of the structural mechanical parts of the prosthesis, assuming that the implants are rigidly fixed bodies. This is not necessarily true, since the bony tissue is elastic. When the abutment screw is fastened, a torsional load appears between the implant and bone. If this torsion is strong enough to break down osseointegration there will be injury to the patient.

Another important aspect resides on the fact that the knowledge of the internal tensions resultant of the assembly of the prosthesis allows the professional to take measures to avoid overload before the prosthesis enters in function by mastication, avoiding also the occurrence of screw losses and break downs.

The body of information gathered by this research supports tests and analysis performed with the prosthesis structure in place as well as numeric analysis of load distribution.

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