EVOLUTION OF THE BACKLASH OF METAL INSERTS THREADED METAL-BONE

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Abstract: *Mechanical Engineering has supplied to Medical Sciences new technologies in oral and chirurgical rehabilitation processing, in which the patients can recover their functionality, self-esteem and healthiness. This paper aims to do an analogy of screw-loosening considering the backlash evolution as a function of number of cycles of impacts, effect which is completely undesirable in a metal-bone union. The experimental test rig developed constitutes a Mechanical Simulator which uses bone specimen, since its bone structure has analogous properties relative to humans. For this purpose, maxillary bones of pigs are used to simulate analogous human bones. Scientific bridges between Engineering and Odontomedical fields have developed methods that contribute to solve uncomfortable injuries as those caused by the use of an implant (screw-loosening, screw-fracture, base-fracture and so).*

Keywords: *Joint, Metal-bone, Backlash, Masticatory test rig*

1. INTRODUCTION

The Tribology is the Science which studies the friction, the wear, the lubrication and the life of the components in mechanical systems. In its scope are inserted increasingly rehabilitation processes in living beings. Among the interactions that this area comprise are those which occur when there is substitution of a part of a living being for a prosthesis, such as implants, where mechanical behavior influences directly the structure where it is attached. For this reason, they have to be exhaustively investigated.

The first implant using screw was developed by the North American Dentist Dr. Linkow in 1963. Nowadays, in the USA, there are about 3.500 professionals working in the area, most affiliated to the American Society of Implant and Reconstructive Dentistry, ASIRD. In Brazil, about 800 professionals are acting in the area, involving between one and two million annually of components of dental prosthesis in the country (CFO, 2014).The global dental implants & prosthetics market is expected to reach $10.427,7 Million in 2020 and is poised to grow at a CAGR of 7.2% during the forecast period of 2015 to 2020 (Marketandmarket, 2014).

According to Levin (2014), there are several factors which contribute to the choice of using implant by the patients. The quality improvement and the easiness of use enter in this ensemble. The durability is much higher too. The aesthetic aspect is also very influential factor because the population is increasingly looking for ways to maintain a youth and attractive appearance.

With the increasing number of implanted, it was realized the importance of studies in conjunction with the engineering about the problems that can be presented in the structures. One of the problems is the occurrence of the *Backlash*, which influences directly the mechanic of the metal-bone set, which may compromise the useful life of the implant. In order to measure this Backlash in function of the number of impact cycles, the Mechanical Simulator was developed in order to request cyclical and mechanically a screwed metal component in a specimen formed by pig bone.

In the literature, there are analogies between the human and others mammals bone structure. Because of that, it was used the swine structure (Aquino et al, 2015).

1.1. Backlash

In the area of Engineering, the term is linked to “the gap between gears, the retreat of a component of mechanical system, the lost movement between two elements of a mechanism, the dead space, the unwanted movement in a control system, when occurs a momentary interruption of applied power, when is verified an alteration in the operating speed”. (Kohara, 2015)

The gap between gear teeth is undesirable in mechanical systems since it can cause microcracks, accumulation of unwanted material, creating a propitious place to corrosion, leading to embrittlement, deterioration and intensification of dynamics phenomena. In the case of implants, this unwanted material may be body fluid which besides help form a propitious place to corrosion, also form, according to Passo (2013), a propitious place to the proliferation of bacteria, which will deteriorate and weaken the implant.

1.2. Metal – Bone

The elucidation of the metal-bone couple’s behavior, mainly about the implants in humans, is extremely important, since this will affect directly in the proper mechanical operation of the structure in which it is linked. The presence of something, for example, Backlash, which does not permit the adequate performance is undesirable.

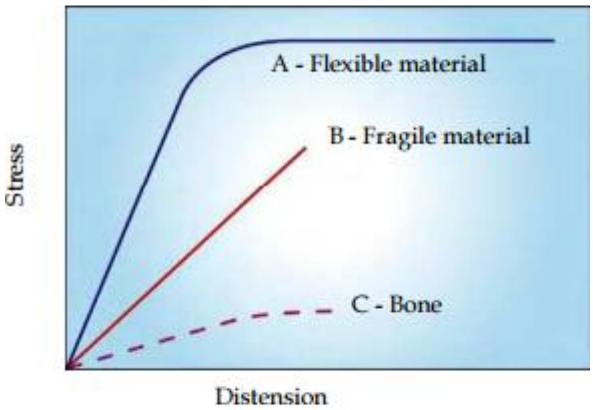
This gap phenomenon, in this case, is due to, basically, the difference of rigidity between the two materials. As the metal has a Young’s Modulus of 200 GPa, the cortical bone has a Modulus of 13.9 GPa as follows in Table 1, due to this difference, the bone will deform before the metal, since the bone is less rigid.

Table 1 - Values provided by Synthes® for stainless steel F138.
Source: Soni *et al*, 2008. (Adapted)

Material	Young's modulus (E), MPa	Poisson's ratio (ν)	Ultimate stress of resistance to compression (σ^-_{ult}), MPa	Ultimate stress of resistance to traction (σ^+_{ult}), MPa
Stainless steel (F138)	200,000	0.33	500	500
Titanium	105,000	0.34	750	750
Cortical bone	13,700	0.30	224	151
Trabecular bone	7,930	0.30	80	-

The difference of the mechanical behavior due to the rigidity of these materials can be better visualized in Figure 1. According to Bankoff (2012), the bone has a viscoelastic behavior, it may behave as ductile or brittle, depending on the load application speed.

In the Stress-Stain diagram, Figure 1, the viscoelastic material sometimes has ductile behavior, sometimes brittle, because it shows a short plastic deformation before the rupture, which is not enough to be considered the first cited, but enough not to be considered the second one.



Examples:

A – Steel
B – Ceramics

Figure 1 – Stress-Stain Diagram to an (A) Ductile, (B) Brittle e (C) Osseous material.
Source: Bankoff, 2012.

2. MATERIALS AND METHODS

The test follows the standardization used by Aquino (2016). Briefly, the procedures performed was:

a) Acquisition of pig jawbone bone;;

b) Cutting and mounting of the bone;
c) Confection of hole (3 mm diameter) and insertion of a threaded screw in the bone
d) Tests;
e) Dimensioning of holes after test.

The holes were drilled in three directions (E_1, E_2 and E_3), which are represented in Figure 2. The samples nomenclature was based on the direction of the hole of each specimen, for example, E1_1 specimen, is the first specimen made in the direction E_1.

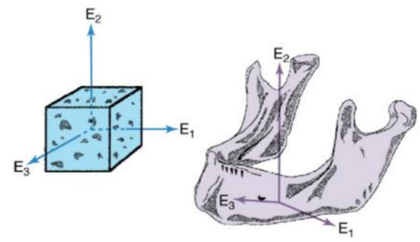


Figure 2 – Directions of the holes to test.
Source: Misch, 2012.

The measurement of the holes was realized at the Computer Aided Design (CAD).

Each test was performed in the Mechanical Simulator (Figure 3) with 6 specimens under a cyclic load of 10.33 Hz (620 RPM) until 10^5 cycles (2h42min test, approximately) with accompanying of the sound pressure level made by a decibel meter - MSL-1352C model.

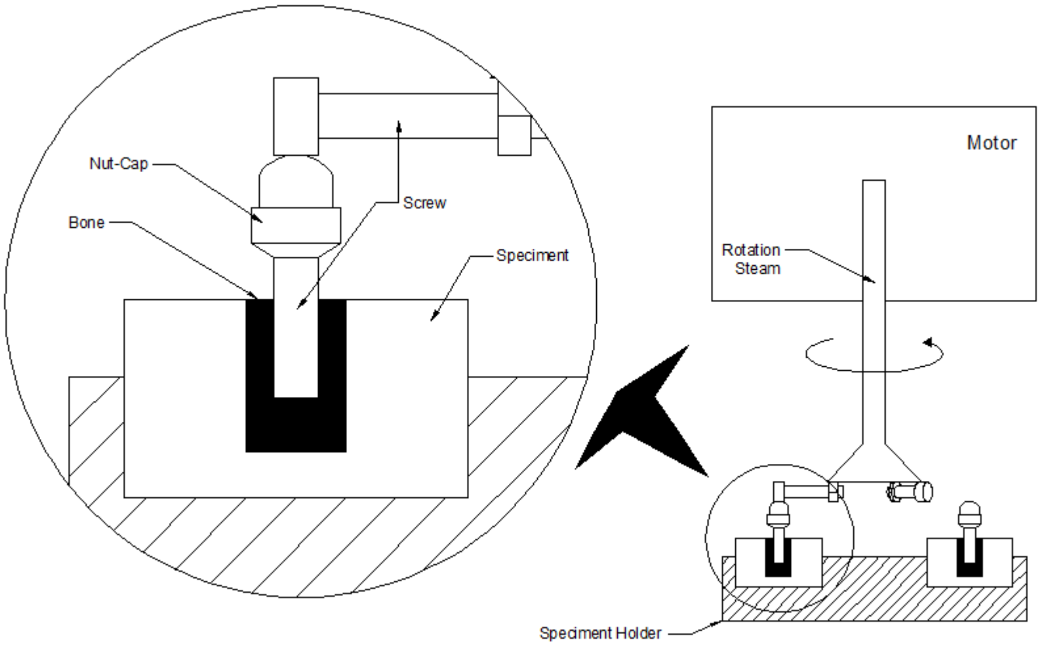


Figure 3 – Mechanical Simulator used in the tests.
Source: Sousa, 2016.

3. RESULTS
3.1. Backlash

To quantify the Backlash, it was defined to be the gap brought about after cyclic loading. This clearance was calculated by the difference in diameters before and after the test (Equation 1). This equation was developed by the authors who understood it as satisfactory.

$$B = D_i - D_f \quad (1)$$

Where:

B: Backlash D_i : Initial Diameter D_f : Final Diameter

The initial diameter to all specimens were 3,000 ± 10 µm. Using the Equation 1 to three different specimens was obtained the Table 2. The behavior of the specimens with the same hole direction were very similar, and because of that, were exposed only one for each direction here.

In Table 2, it is found the mean Backlash values and their specimens. The "Backlash" column refers to the maximum distance moved in the mechanical system, following the definition of Bagad (2008).

Table 2 – *Backlash* - Graphical Measurement.

Specimen	**Mean Backlash (µm)**	**Backlash (µm)**
E_1_5	403	600
E_2_5	488	590
E_3_5	25	35

An example of how the diameters were measured before and after test is shown in Figure 4.

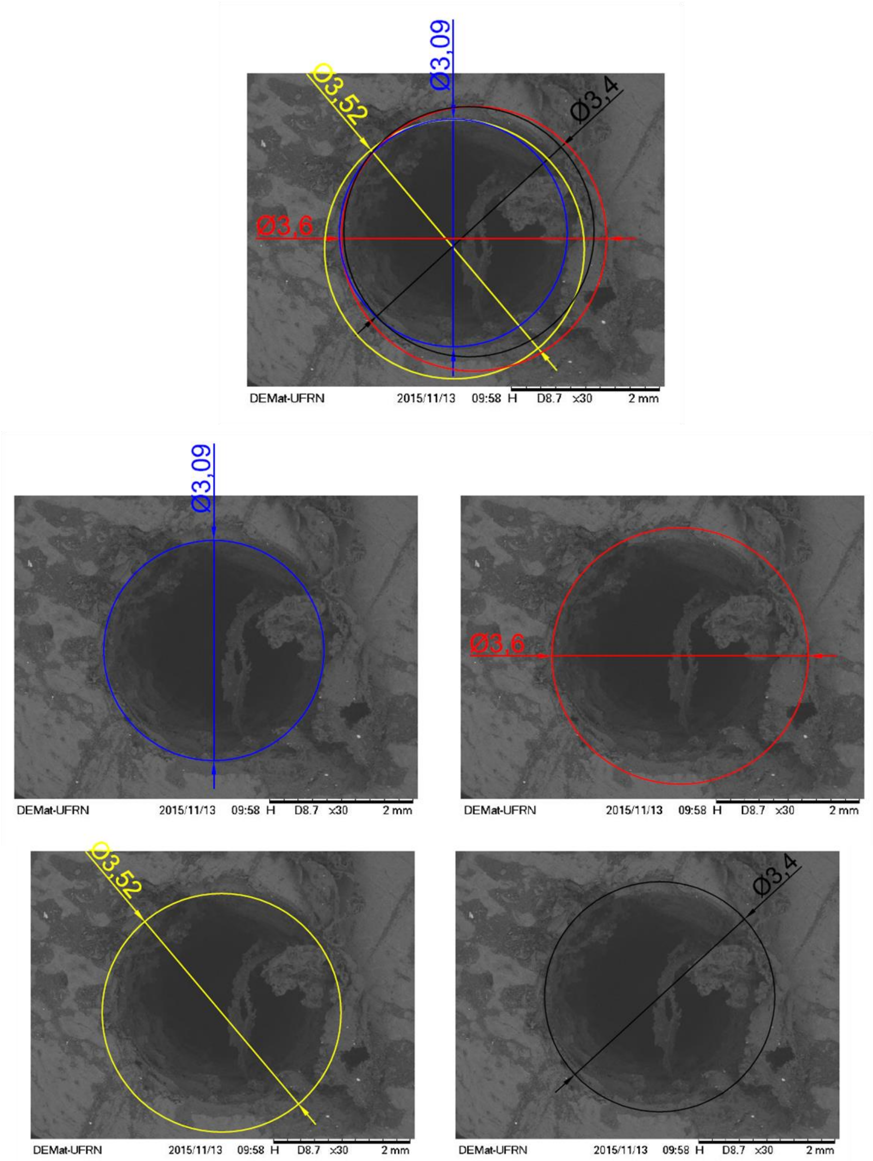


Figure 4 – Hole's diameter after test. Specimen E_1_5. Mean Backlash of 403 µm.
Source: Sousa, 2016

It was also evidenced the presence of cracks in the surface structure of the bone used in the specimen, having as one of the wear mechanisms in the system the brittle fracture, probably associated to the cyclical request, damage shown in Figure 5.

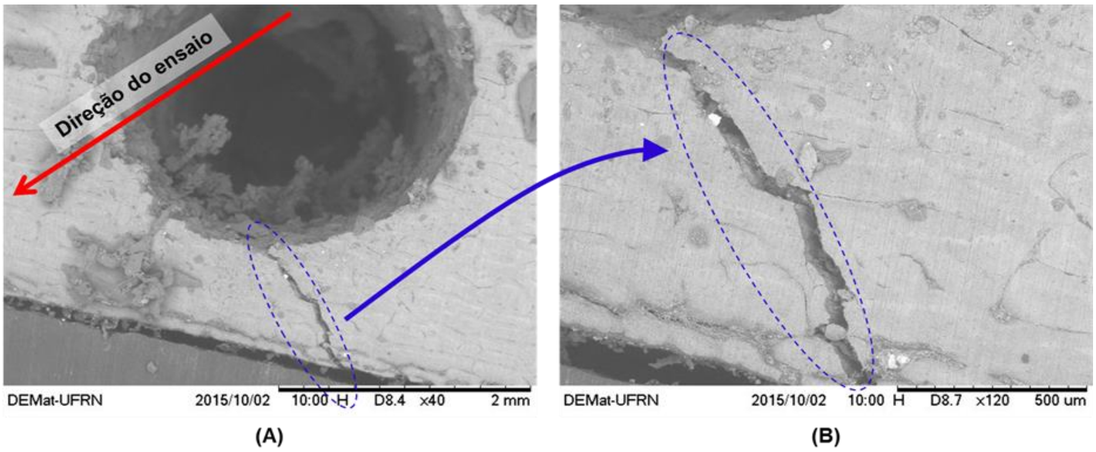


Figure 5 – Wear by fatigue evidenced by crack growth. Specimen E_2_5. (A) 500x e (B) 3.000x.
Source: Sousa, 2016.

3.2. Sound Pressure Level, SPL [dB]

An indicator widely used in research on the mechanical system and the evolution of the damage on their surfaces is the analysis of the SPL, sound pressure level. During the test, it was possible observed changes in the behavior of this variable (Aquino, 2016) and, therefore, infer, among other things, the acting contact mechanism.

The Figure 6 shows that during the test there is a running-in regime, 0-10^4 cycles, associated with the accommodation of the contact between the surfaces. In the second part analyzed, 10^4-10^5 cycles, it can be noticed a relative decrease in the values of sound pressure level, showing the steady-state.

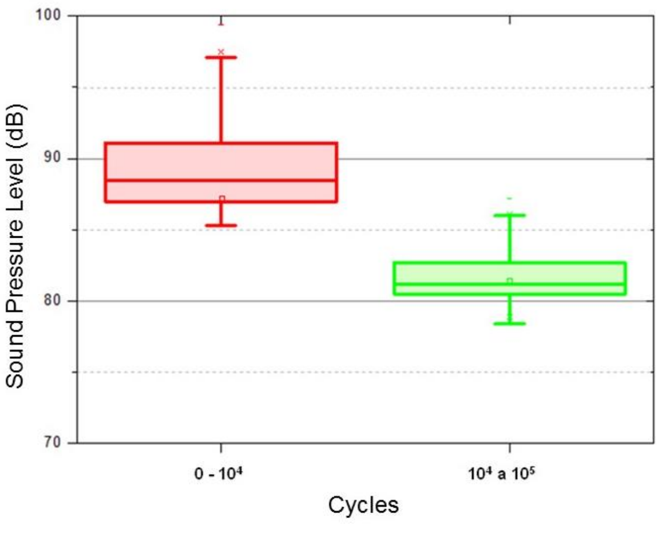


Figure 6 – Sound pressure level during cyclic mechanical testing.
Source: Sousa, 2016.

4. DISCUSSION

It was observed that in two of three directions, Backlash had the same order of magnitude. In the third bone direction, the magnitude of Backlash was thirty times smaller. This reaffirms the analogy made by Aquino (2016) since it is observed the characteristic of a transversely isotropic bone, which is a material that has in two of the three directions the same mechanical property (Misch, 2015), which it is also a characteristic of the human jawbone.

According to Medeiros (2002), you can monitor the evolution of wear by the sound emitted by the irreversibility of a cyclic contact. The sound pressure levels of the tests, seen in Figure 6, legitimize the change of existing contact, changing from nonconforming contact, 0-10^4 cycles, to conforming contact, which evidence the lowering of the sound pressure level, following the same trend of Hertz contact pressure.

For this system, the presence of Backlash is not desired, considering that in a living system this gap would cause proliferation of bacteria and corrosion sites. So the solution would be to use implants in bone direction that resists more (E_3), which is not possible due to the geometry and purpose of it.

The presence of brittle fracture was caused by cyclic stress for a long duration, expected damage occur during the tests.

In practice, it is expected that this clearance became lower, since in the experiments performed the bone is dead and therefore does not present the osseointegration, very important factor, since the bone is "regenerated", thereby decreasing Backlash.

5. CONCLUSION

After the tests performed according to the methodology described in this work relating to the testing of a pig jaw bone, subjected to a drilling process, insertion of a threaded screw and cyclic mechanical test up to 10^5 cycles, it was inferred that:

1) The Backlash phenomenon had had its intensity increasingly enlarged during the test;
2) The pig bone, as the human bone, is transversely isotropic and, in its third dimension, the Backlash is thirty times less than in the first two directions.

6. ACKNOWLEDGEMENTS

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8. AUTHORAL RESPONSABILITY

The authors are solely responsible for the content of this work.