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WEAR IN PROSTHETIC IMPLANTS: MASS LOSS, GVS AND SPL ON DIAGNOSTIC OF PH INFLUENCE ON METAL-PORCINE BONE UNION DURING MECHANICAL MASTICATORY PROCESS

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Abstract. *The Mechanical Engineering supplies new technologies to Odontomedical Sciences in oral rehabilitation processing, in which patients can rescue their self-esteem and welfare. In this investigation, pig jawbones are used to simulate human bones by homology, focusing on the wear. Knowledge bridges between specific fields of Science seeks to develop methods to reduce future problems caused by using an implant (screw-loosening, screw-fracture, base-fracture and so). In this paper, it is intended to help implants professionals to better understand the wear and its impacts on the implants by taking into account generally underestimated bone reaction to the pH environment, especially in dentistry that has huge variation due to different feeding. For the procedure, firstly, wear in different pH environments have been investigated and secondly its impacts on the backlash phenomena both in function of the number of cycles. Wear rate by mass loss and Backlash were discussed. Aiming help this assessment, Sound Pressure Level (SPL) and Global Vibration Speed (GVS) were also analysed. It was observed that an basic environment is the best when the main objective of the implant is to be firm since this environment provides an smaller backlash phenomena.*

Keywords: *Wear, Bone Implants, Jawbone, Screw, pH.*

1. INTRODUCTION

Bone is a structural hierarchical composite, mainly made of hydroxyapatite crystals and collagen matrix, and showing a complex organization at different length scales. It is well-known for its optimal combination of mechanical properties, and in particular for its remarkable toughness, explaining why it provides supports for many organisms (Vergania *et al.*, 2014). Thanks to its outstanding mechanical properties, combined with a low weight, bone constitutes a source of inspiration for the design of new tough nanocomposites. The fracture behavior of human bone is an interesting field of research for medical scientists (Nalla *et al.*, 2003; Ritchie *et al.*, 2004), which are interested in predicting the fracture risk, but also for engineers, which are concerned in mimicking bone structure (Espinosa *et al.*, 2009) in the design of new materials. Indeed for the clinicians, predicting and understanding wear for individual patients is crucial.

With technological development and increased access to information, it has become possible to correlate areas previously seen as unconnected. An example is the recent partnership between Engineering and Medical Sciences. The metal implants area growth was determined mainly by demand for attempts to repair bone, usually by internal fixation of long bone fractures (Manam *et al.*, 2017).

How the pH environment affects an bone structure? Most of the previous studies have been adressed on teeth that were destroyed after immersion in hydrochloric acid, phosphoric acid and sodium hydroxide at concentration reasonably found in household cleaning products (Mazza *et al.*, 2005; Jadhav *et al.*, 2009; Cope and Dupras, 2009). In a further study performed on teeth (Raj and et al, 2013), the corrosive capabilities of 37% hydrochloric acid, 65% nitric acid and 96% sulfuric acid was tested in 8-h time inteval. The only study available on this kind of issue on teeth and other tissues (bone, hair, nails and soft tissue) was performed by Hartnett *et al.* (2011) with hydrochloric acid, sulfuric acid, lye bleach, organic septic cleaner and cola soda at various concentration and for different immersion times. Further studies have been performed on the effects that different pHs may exert on human bone in freshwater environments (Christensen and Myers, 2011) and in different types of soils (Haslam and Tibbett, 2009).

In this paper, it is intended to help implants professionals to better understand the corrosion and its impacts on the implants by taking into account generally underestimated bone reaction to the pH environment, especially in dentistry that has huge variation due to different feeding. Furthermore, the number of implants and its preference in relation to prostheses have been growing every year in Brazil, according to Odontology Federal Council (CFO, 2014). For the procedure, firstly, wear in different pH environments have been investigated and secondly its impacts on the backlash phenomena both in function of the number of cycles. Wear rate by mass loss according to ASTM (2011) and the Equation defined by Sousa (2016) are used to asses Wear and Backlash, respectively, however, for the gap phenomena it was just made a connection to the results obtained in this work. Aiming help this assessment, Sound Pressure Level (SPL) and Global Vibration Speed (GVS) were also analysed. Following this introductory part, experimental procedure in detail are given in Section 2. Results and Discussions are in detail in Section 3 and 4, respectively. Finally Conclusions in Section 5.

According to Medeiros (2002), the contact energy between mechanical components is transported in the middle and is closely related to the sound pressure level (SPL). Thus, the collisions between the stem-implant assembly used in the test developed in this work can be studied as a function of the SPL intensity. Similar analogy can be done to Global Vibration Speed (GVS).

2. EXPERIMENTAL PROCEDURE

The experimental procedure is divided into steps seen in the flowchart of Figure 1.

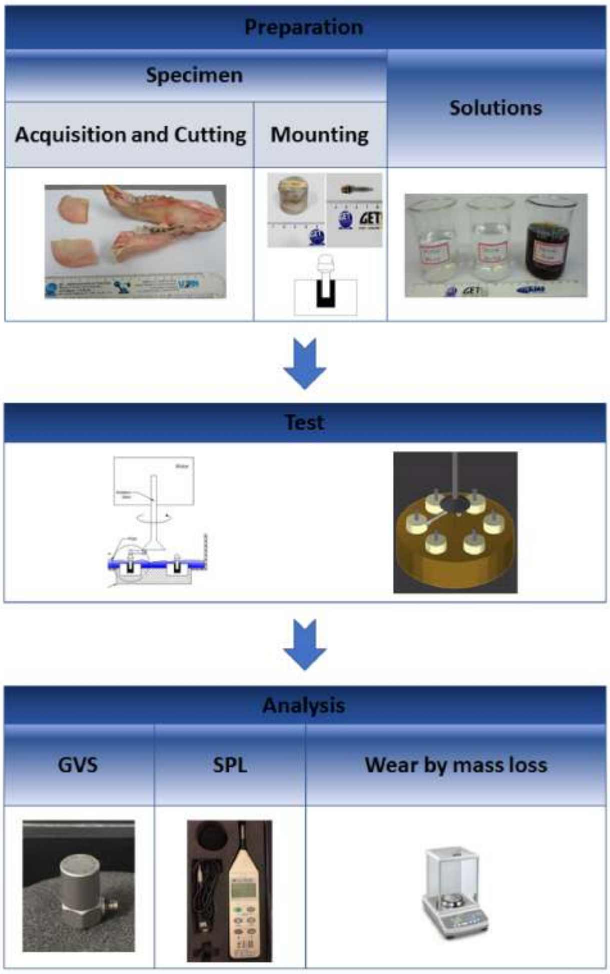

Figure 1: Methodology steps flowchart.

2.1 Specimens

In the tests was used the swine bone instead of human bone due to the easy acquisition. Moreover, in the literature, there are analogies between both structure (Sousa *et al.*, 2015). All the pig jawbone were approximately twelve months old. A total of 36 samples of porcine bone (jaws of *Sus scrofa*) 15 x10^{-3} m in height and 25 x10^{-3} m length, were completely skeletonized and cut manually with the use of a mechanical saw without any chemical treatment, in order to best preserve the outer and inner structure of the samples.

Specimens were then divided in six groups, shown in Table 1, and immersed in acid solutions (Aci), basic (Bas) and neutral (Neu), with and without mechanical simulation. Specimens were named according to its test pH environment and its confection number, thus, each test body received the following nomenclature: pH-number. For example, "Aci-1" is equivalent to "Specimen number 1, tested in acid solution".

For the abutment, the material used was the Polidyne® 5061 colorless unsaturated polyester resin due to its low reactivity and rapid preparation, and a self-polymerizing liquid. The process resulted in a cylindrical insert with a diameter of 31 x10^{-3} m and an approximate height of 20 x10^{-3} m. For simulate the implant, an Phillips flat head bolt of carbon steel was used, welded to a 7/16 "(5.4 x10^{-3} m) hex nut cap, thin thread, high blind nut, made of AISI 304 stainless steel, both commercially purchased. The screw was used due to its similarity to that of titanium used in dental implant dentistry, but at lower cost. The pair was grouped by Oxyacetylene brazing, developed at the Materials Laboratory of UFRN.

Table 1: Specimens.

	With Mechanical Simulation			With Mechanical Simulation		
Specimen	Acidic	Basic	Neutral	Acidic	Basic	Neutral
CP1	Aci-1	Bas-1	Neu-1	Aci-7	Bas-7	Neu-7
CP2	Aci-2	Bas-2	Neu-2	Aci-8	Bas-8	Neu-8
CP3	Aci-3	Bas-3	Neu-3	Aci-9	Bas-9	Neu-9
CP4	Aci-4	Bas-4	Neu-4	Aci-10	Bas-10	Neu-10
CP5	Aci-5	Bas-5	Neu-5	Aci-11	Bas-11	Neu-11
CP6	Aci-6	Bas-6	Neu-6	Aci-12	Bas-12	Neu-12

2.2 Test

In order to reach the objectives of this study was developed a test rig (*O Simulador Mecânico de Processo Mastigatório Unilateral Cíclico* ;the Mechanical Simulator of Cyclic Unilateral Masticatory Process - SIMPROM-UNIC® - Figure 3).

The test consists in a mechanical simulation with unidirectional load with 620 RPM where the specimens are attached by Allen screws into a cylindrical structure with six holes spaced at 60º (Figure 2). The environment was maintained in an air relative humidity range of 50% ± 10. The correct positioning between the stem and the specimen holder was ensured for a concentricity deviation of at most 2%. The whole "support - specimen" used in the mechanical simulation with unilateral loading follows this configuration shown in Figure 2.

It was used the semi-submerged condition on fluid to simulate different mediums which this type of implant may experience. The fluids were: Acidic solution (Soda - Cola; commercially available), basic solution (Sodium hydroxide solution - NaOH; 1 molar) or neutral solution (distilled water). In Figure 3, how the samples were semi-submerged can be better understood. The total test time was of 2h42min (10^5 cycles).

2.3 Analysis

At the beginning and end of each test partially immersed with the acidic, neutral or basic solution, the pH was checked with pH indication tape with range from 0 up 14 and pH-meter DM-22 at the Nucleus of Research in Oil and Gas Laboratory in the Department of Chemistry Engineering of UFRN. Also before and after tests, the specimen are cleaned in an ultrasonic bath with Propanone, as known commercially as acetone, for 10 minutes (1/6 hour) for the removal of less adherent corrosion products on its surface. Finally, they are dried in hot air and weighed in analytical balance (brand Tecnal and model B-TEC-210 A; tenth of milligram precision). It were used a decibel meter model MSL-1352C and a instrument of vibration analyser model NI 9234 - National Instruments - to investigate Sound Pressure Level (SPL) and Global Vibration Speed (GVS), respectively.

To investigate wear by mass loss, pre and post-test mass measurements were made. The wear rate of mass loss was calculated by Eq. (1) according to ASTM (2011):

$$TC = \frac{K.W}{A.t.D} \tag{1}$$

where

TC – Wear Rate (mm/year)	A – Area (cm^2)
K – Constant (8,76 x 10^4)	t – Exposure time (h)
W – Mass Variation (g)	D – Specific mass (g/cm^3)

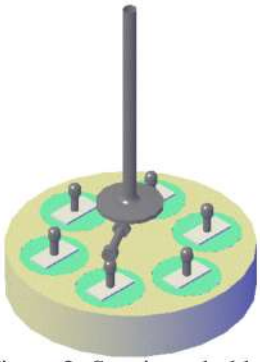

Figure 2: Specimen holder.

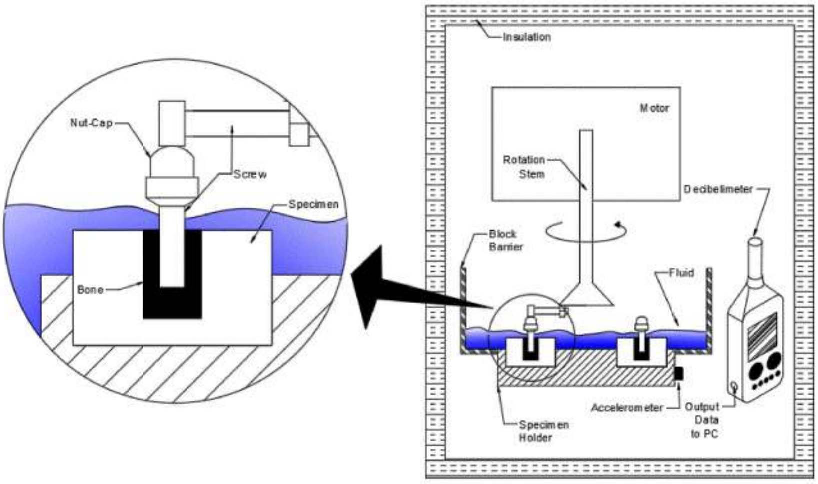

Figure 3: Mechanical Simulator of Cyclic Unilateral Masticatory Process (SIMPROM-UNI®) schematic representation. Adapted from Pontes (2016).

3. RESULTS

The main results from this paper are presented in the Figures 4 and 5.

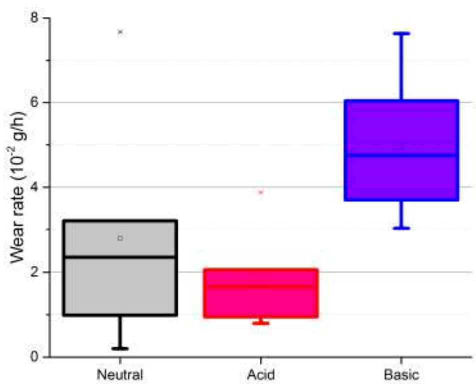

Figure 4: Wear rate by mass loss.

3.1 pH Neutral

Wear rate: It presented an average wear rate, as well as a non well-divided behaviour as can be observed between first and third quartiles in Figure 4. *Sound Pressure Level:* As in GVS, there was a decrease in dispersion and mean value. There was also a general mirroring by the median. *Global Vibration Speed:* Until 10,000 cycles was observed an high

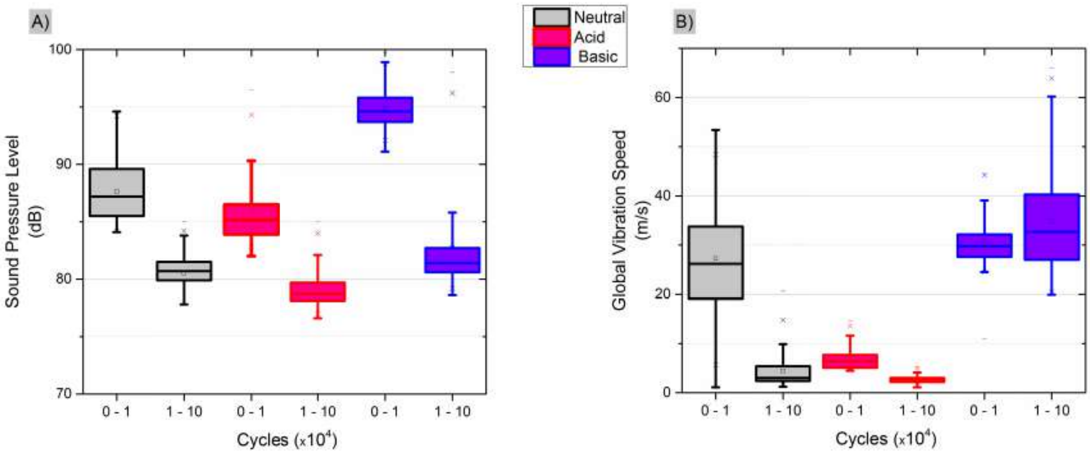

Figure 5: Specimens group parameters as a function of number of cycles. A) Sound Pressure Level; B) Global Vibration Speed

dispersion with mean value about 26.6 m/s. From 10,000 up 100,000 cycles is observed a considerable decrease, both in the mean value (to 4.2 m/s) and the dispersion.

3.2 pH Acid

Wear rate: It presented an relatively low wear rate, as well as a non well-divided behaviour as can be observed by the regions limited by upper limit and third quartile, and lower limit and first quartile in Figure 4. *Sound Pressure Level:* As in GVS, there was also a decrease in mean value, however, it isn't observed in dispersion. *Global Vibration Speed:* Until 10,000 cycles was observed a high dispersion between upper limit and third quartile with mean value about 5.7 m/s. From 10,000 up 100,000 cycles is observed a decrease, both in the mean value (to 2.4 m/s) and the dispersion.

3.3 pH Basic

Wear rate: It presented an relatively high wear rate, the biggest between the different environments, besides it presented a well-divided behaviour as can be observed between first and third quartile in Figure 4. *Sound Pressure Level:* As in GVS, there was a decrease both in mean value and in dispersion, however, lesser in this last parameter. *Global Vibration Speed:* Until 10,000 cycles was observed an low dispersion and a mean value about 31.2 m/s. From 10,000 up 100,000 cycles is observed an increase, both in the mean value (to 35.1 m/s) and the dispersion, mainly between upper limit and third quartile.

4. DISCUSSION

The surface roughness, topography, and chemistry are factors that influenced the results among the couple screw-bone of same group (Subramanian *et al.*, 2012; Parsapour *et al.*, 2012; Sammons, 2010) and these can be one of the responsible for the observed dispersion.

The lowest wear rate for pH acid is probably due to the lesser contact between the stem and the screw "implant" due to the backlash induced by the formation of cracks as observed by (Amadasi *et al.*, 2015). As we would predict, crack originated in the region of maximum stress concentration, close to the hole, several crack originated in this region and propagated parallel to the applied load. This phenomena was also responsible for SPL reduction and the general low GVS. This condition also induced the changing of the surface making it softer, and therefore, presented the lowest values for GVS and SPL.

Different from the other environments, the pH basic does not presented a reduction on GVS. According to (Amadasi *et al.*, 2015), this pH condition accelerate the decomposition of the periosteum, a membrane that covers the outer surface of all bones, and this removal could have caused the reduction on the ability to absolve energy allowing the embrittlement and breaking of particles, thereby facilitating the formation of a three-body system, which in turn has a higher vibration level due to the higher friction.

4.1 pH

Only the acid medium presents a significant pH variation, it was expected since soda was used, and over the cycles, the present gas in the internal medium would diffuse and migrate to the external medium, however, the variation was higher than expected (5 times higher - changing of pH range from 2 to 3).

4.2 Clearance in the Screw

The clearance in the screw hole increased during the tests and was quantified by Backlash, which is not interesting for the bone-screw system, because in living systems are possible points for bacteria proliferation (Pontes, 2016; Sammons, 2010).

5. CONCLUSIONS

After tests, which were performed according to the methodology described in this work, relating to testing a swine jawbone with approximately twelve months old, subjected to a drilling process in the bone, insertion of a threaded screw and cyclic mechanical test immersed in fluid up to 10^5 cycles, it was inferred that:

1. The pH had a great influence on the wear due to its performance on the behavior of the used structure (swine bone);
2. The acidic pH provokes an fast backlash development, which reduces the wear rate when compared to basic pH;
3. The wear increased by the number of cycles, influencing the backlash of the fit between screw and bone in a directly proportional way;
4. Soda as an acid medium, although representing a real condition well, is not suitable for continuous labor studies due to its difficult modeling for pH variation during tests.

Therefore, it is advisable an basic pH when the main objective of the implant is to be firm since this environment provides an smaller backlash phenomena.

For further studies, we suggest to better understand the phenomena of crack initiation and its further growth in different pH environments, in order to prevent catastrophic failure or backlash of the implant. It is also suggested to study the influence of the bone quality which is in turn dependent on several factors (i.e. genetic disorders, ageing).

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE

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