Comparison of mechanical behavior between implant-simulated bone tissue and implant-jaw bone tissue interfaces based on Pull Out testing

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Abstract. The main purpose of this research was to achieve a better understanding of the relationship within the mechanical properties of human cadaver jaw bone with kind D2 density regarding a substitute polymer to simulate bone tissue, proposed by the ASTM, to evaluate orthopedic implants. However, despite the existence of several densities of foams and his mechanical characterization has been classified into different degrees of tissue densities to simulate cancellous and cortical bone, the value of the densities are different contrasted with the densities of bone tissue, making difficult to establish direct relationship about mechanical behavior between the polymer and the bone material, and therefore no clear criteria known for choosing the polymeric foam which describes the mechanical behavior of tissue for a specific or particular study. To understand such behavior from bone tissue regarding the polymer samples, on this research was a dental implant inserted into the samples, and subjected to destructive Pull Out test according to ASTM F543. The Pull Out strength was compared between implant-jawbone and implant-rigid polyurethane foam interfaces. Thus, the test pieces with mechanical behavior similar to bone tissue, enabling an approximation to choose degree appropriate of polymer to replace the bone tissue in future trials biomechanical.

1. Introduction
The scientific community has developed studies based on design, materials and biomechanical analyzes of dental implants for replacement of dental roots. These biomechanical studies are performed to validate the design of the implant. Nevertheless, the jaw bone is formed by cortical and trabecular bone with a percentage of occurrence that depends of their biomechanical function on the jaw arch [1], for example, in the molar region the percentage of cancellous bone is higher than cortical bone tissue, so that its density is of type D2 and D3, according to the clinical classification dental [2].

However, due to the destructive nature of the biomechanical testing, ASTM suggest that destructive testing with implants for any product that requiring the use of bone tissue, the bone must be replaced by a polymer specimen developed to simulate bone tissue (Rigid Foam polyurethane) [3]. Nevertheless although it is known that bone density is related to the mechanical strength [1, 2], there is no coincidence between the mechanical and physical properties of bone tissue with respect to the polymer, whereby it is not possible to establish selection criteria describing the mechanical behavior equivalent to bone tissue. However, a way to know the interface strength between implant and bone specimen’s polymer is through destructive test Pull Out [4], which was proposed in this paper to establish by comparison, the similar mechanical behavior between bone tissue specimens and specimens of polyurethane.
From mechanical testing set out to establish a relationship of the kind of density jaw bone sample with the bone specimens simulated. In the following sections describe the materials used in mechanical testing, methodology, results and discussion of results.

2. Methods and materials

The first step was design a dental implant to molar region, with 12 mm length and 5 mm diameter, threaded body type HB, ASTM [4]. The implant was made of Ti6Al4V alloy [5] by specialized surgical company. Subsequently, were used three specimens of human cadaver mandible in the molar region, the material was supplied and prepared in the legal medicine laboratory of the Faculty of Health Industrial University of Santander; in turn, the bone specimens were characterized by technique imagediagnostic [6], so the tissue density of molar region was identified as D2 type 2gr/cc3 [7]. Polymer samples were chosen to simulate trabecular bone density type using G12, G15, G20, G20/12, cortical bone density and type G30, G30/12, G40/10, G40/12, ASTM F1839-08 [3]; for each specimen degree were performed three experiments, data on polymer characterization of the samples were provided by the manufacturer Sawbone® [8] (see table 1).

The implants were inserted in the samples through a digital torque wrench [9]. Subsequently the samples were subjected to Pull Out destructive test, based on ASTM F543 used to measure the magnitude of the insertion force generated by the contact surface at the bone-implant [10], through the application of an axial load until remove the implant from the specimen [11]. The tests were made in the laboratory GIMAT; the assemblies were tested in the universal testing machine from Tinius Olsen 50KN load [12]. In figure 1 left, it sees the image of the specimen located on the universal testing machine Tinius Olsen. Figure 2 corresponding to the central image that shows the dental implant machined in Ti6Al4V inserted into a Sawbone® specimen's; the image was taken under microscope KH-7700 HIROX [13], in laboratory GIMAT research group. Finally in Figure 3 shows the removed implant bone interface like result of the Pull Out test.

3. Results

Once were made the assay, from these were obtained the extraction load values and displacement data on the implant interface, from this data was calculated the elastic limit stress, strain, Young's modulus E and Max. Stress, as shown in table 1. Likewise, the mechanical behavior of the specimens was plotted in figure 4 by the graphic Force / Displacement. Specimens like G12 at G20, with supposed mechanical strength similar to graphic "bone", were again plotted for comparative purposes, like seen in figure 5. Thus, were identified the specimens with mechanical behavior similar to bone.
Table 1. Physical and mechanical properties characterization based on Pull Out test.

| Specimen | Density (gr/cm³) | Strain (elastic limit) (mm/mm) | Load/Elastic Limit (N) | Sy³ (MPa) | E⁵ (Gpa) | Strain Max. Load (N) | Max. Stress (MPa) |
|----------|-----------------|-------------------------------|------------------------|-----------|---------|---------------------|-------------------|
| Bone     | 2.0             | 0.005                         | 190.8                  | 9.71      | 1240.8  | 0.037               | 336.0             | 17.1             |
| G 12     | 0.2             | 0.021                         | 106.1                  | 5.40      | 331.3   | 0.046               | 151.6             | 7.7              |
| G 15     | 0.2             | 0.011                         | 140.5                  | 7.15      | 476.1   | 0.030               | 184.0             | 9.3              |
| G 20     | 0.3             | 0.019                         | 223.9                  | 11.40     | 729.9   | 0.040               | 323.8             | 16.3             |
| G 20/12  | 0.2             | 0.012                         | 133.2                  | 6.78      | 475.2   | 0.070               | 321.6             | 16.4             |
| G 30     | 0.4             | 0.003                         | 48.0                   | 2.44      | 351.0   | 0.100               | 734.2             | 37.3             |
| G 30/12  | 0.2             | 0.006                         | 67.5                   | 3.43      | 256.7   | 0.170               | 489.0             | 24.9             |
| G 40/10  | 0.1             | 0.007                         | 39.2                   | 1.99      | 218.0   | 0.100               | 129.2             | 6.5              |
| G 40/12  | 0.2             | 0.009                         | 22.4                   | 1.14      | 82.9    | 0.130               | 270.0             | 13.7             |

³ Stress Yield
⁵ Young’s Modulus

Figure 4. Outcomes assay according to Pull Outtest, Graphic force/displacement of total.
4. Discussion of outcomes
The pull out tests made in this study allowed to know the mechanical behavior of specimens implant interfaces by which it was possible to establish the mechanical behavior of the implant extraction resistance at the interface between the specimens G 20, regarding bone specimen. Thus, it was established for these experiments that the G20 grade specimen has a relation with the mechanical properties of bone mandibular molar region D2 density type, so it was possible to select this grade of specimen for future experiments based on experimental and simulation tests.

Further testing is required for the samples with G20 density combined with lower density than grade G20, to establish a suitable selection because there was no enough consensus regarding the mechanical behavior in each of the tests.

It is recommended to extend the study to bone densities D1, D3 and D4 Kind according classification proposed by Misch, thus establishing a direct link between the sawbone® specimen and the bone tissue, because these outcomes will be useful in selecting suitable polymeric material to replace living tissues in others physical and mechanical destructive test.

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