Analysis of the Response of a Compound Based on Magnetic Nanoparticles to the Magnetic Field

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***Abstract*— In order to improve vertebral surgery techniques, it is proposed to use a new formulation of bone cement composed of magnetic nanoparticles. In conjunction with an external magnetic field source, which will be responsible for controlling the transport of this material between the vertebral structures, a significant increase in the efficiency of the pedicle screw fixation is expected, which provides stability to the spine of patients affected by degenerative diseases. Therefore, we characterize both the biomaterial, in relation to the bonding time, magnetic measurements, density, viscosity, cytotoxicity, and the magnet, in relation to the geometry of the magnetic poles, magnetization, and the magnetic field intensity to be applied.**

***Keywords*—nanoparticles; magnetism; biomaterials; characterization; magnets.**

I. INTRODUCTION

The development of nanoscience and nanotechnology has provided the ability to manufacture materials on an ever smaller scale, not always available in nature or in small availability, with well defined electrical and magnetic properties and allowing greater control of their characteristics. Among the many materials developed in the national and international research centers, magnetic ceramics have attracted great interest from many researchers [1].

Ferrites allow to form magnetic nanoparticles, making these materials have a characteristic called superparamagnetism. Theoretically, this material is characterized by presenting magnetization only in the presence of an external magnetic field, that is, it presents zero intrinsic coercivity. This property is directly linked to the size of magnetic nanoparticles (< 30 nm). The closer the spherical shape and the greater the uniformity between forms, the greater the efficiency of the nanoparticles for applicability as ferrofluid. This behavior is attractive for biological applications, since it is still possible to solubilize fluids. This feature increases its ability to move along the fluid , and, consequently, to move within the human body. Ultrafine particle magnetism arouses interest in areas that study systems in which permanent magnetism has potential to be used. For example, its use as a magnetically-driven drug carrier represents an important advance in the use of localized chemotherapy [2]. In this way, the scientific research has turned to the obtaining of materials such as, for example, the ferrites that are part of a large group of magnetic materials under study, which, due to their many applications, arouse the interests of many researchers in studies of new techniques for the preparation of these materials to improve their properties.

In medicine, specialists in spinal surgery inevitably encounter patients with diseases such as osteoporosis, which require decompression of the spine and instrumentation due to osteoporosis (bone metabolism more frequent in the general population) and degenerative diseases, lumbar canal stenosis, disc hernias. fractures and pathological displacements, among others [3]. To date, it is well known that the most effective method for fixation is pedicular instrumentation. In this technique, a screw, especially adapted to the anatomy of the vertebral bone, is used to attach one vertebra to the other, to acquire the stability lost, by a disease or during the surgical act [4] as shown in Figure 1.

Fig. 1. Pedicular screw and its location on the lumbar vertebra.

However, because of osteoporosis, surgical implants present great failure of initial and late fixation. The big problem lies in the bone-screw interface. In the osteoporotic patient, this interface is restricted to poor bone quality [5], [6], [7]. It is evident that the challenge in biomechanical science is the development of a product or instrumental capable of overcoming this difficulty of fixation in an osteoporotic bone. The study of insertion techniques and alternative projects of pedicle screw was motivated by the recognition of potential fixation complications. Previous biomechanical studies have demonstrated that pedicle bolt fixation is highly correlated with bone mineral density [5] and that increases in screw pull resistance are possible using a variety of methods [8], [5], [6], [7], and one of the most used is the addition of bone cements, making it possible to fix screws inside the vertebral body in extremely fragile vertebrae. The use of cement to strengthen the interface between the screw threads and their bony surroundings has proven to be a successful solution as it provides greater stability of the screw in the bone of compromised quality [9].

The process of injection of bone cement into pedicular screws is promising; however, there is a need to better recognize the innumerable variables that modify the biomechanical and clinical outcome [10]. These variables, from the mechanical point of view, can be described as, type of cement used, viscosity, pressure, quantity and speed of injection. From the clinical point of view, macroscopic and microscopic vertebral anatomy, bone density, and bone consistency are selected [11]. Recently the vertebral microstructure and its constituents have been gaining notoriety due to their importance in the biomechanical and clinical result and being the target of analysis [12]. Histologically the trabecular bone is composed of trabeculae that intersect but do not fill the entire space, leaving an area that is contained by brown tissue or bone marrow. The bone marrow is a gelatinous tissue that fills the internal cavity of several bones and manufactures the figurative elements of the blood as red blood cells, leucocytes and platelets.

The neodymium supermagnet is a type of material that has a very powerful magnetic field. When compared to a ferrite magnet, the neodymium magnet offers a mass 18 times higher, reaching greater forces of attraction. This characteristic has increased the demand of this material by the industry for the confection in more compact formats. In this way, the super magnet has a high magnetic attraction force, even in reduced sizes.

This product is usually in the metallurgical, food, chemical, pharmaceutical and other industries to help erect heavy materials or even the removal of ferrous fragments in the form of magnetic brooms, magnetic bats, or even catapes magnets. Its application in this project is due to the high magnetic field and small dimensions. The limitation of the use of the neodymium magnet is in the fact that, although elevated, the magnetostatic field generated does not allow the control of the variation of the intensity of the same. In the control of field strength can be partially solved by distancing the neodymium magnet physically from the bone tissue, which allows only a qualitative control of the field.

On the other hand, a more complex electromagnet, from the electrical point of view, allows to control the magnetic field from the use of DC power supply. Respecting the specifications of time of use, power, supply voltage, volume, type of winding and number of turns, the design of an electromagnet can achieve the characteristics necessary for the control of the field distribution in the surrounding bone-screw desired.

II. CHARACTERIZATION

A. *Preparation of cements*

The composites were prepared prepared using Fe3O4@SiO 2:HA ratio. Initially the Fe3O4 → SiO2 hybrid was previously dissolved in deionized water under constant stirring for 30 minutes using a magnetic stirrer at room temperature. After drying, the composites were deagglomerated in an agate mortar and passed through a 325 mesh (44 μm) ABNT sieve, called C1, C2 and C3, and subjected to characterization. The composites were mixed with polymer additives (carboxylmethylcellulose and glycerin) to provide a cement / hydrogel with adequate melt flow and time to uniformly diffuse and solidify by fixing the screws to the bone, designated G1, G2 and G3.

B. *Bonding Time*

To analyze the bonding time of the cement, a syringe was used to insert 1.0 ml of the fluid into a flat glass surface. Keeping the fluid at room temperature (25 ° C) and natural circulation of air. The time in which the aliquots of the samples hardened to a rigid solid was monitored.

C. *Cytotoxicity*

The cytotoxicity of a sample is determined by the percentage of cells remaining viable after exposure of the cell population to various concentrations of test substance extract. To calculate this percentage a vital dye and an electron coupling agent are used which, when incorporated by the cell, produce a specific staining compound that can be detected by a spectrophotometer. The color intensity resulting from cell uptake is directly proportional to the number of viable cells in culture. A sample is considered cytotoxic if the cell viability (CV) resulting from exposure of the cells to the highest concentration extract is less than 70% (CV <70%).

The test of the samples under study was conducted according to ISO 10993-5 (Biological Evaluation of Medical Devices -part 5 -Tests for in vitro cytotoxicity) and ISO 10993-12- (Biological Evaluation of Medical Devices -part 12: Sample preparation and reference materials) in which Chinese hamster ovary cells of the CHO-K1 strain (ATCC CCL-61) were used. The reference materials used were HDPE (negative control - non-cytotoxic) and latex (positive-cytotoxic control).

D. *Density*

Density of the liquid cement / hydrogel was determined at room temperature (25ºC) with the Anton Paar densimeter model DMA 35. For solid cement samples it was performed by pycnometry of helium gas on an Upyc 1200e v5.04 Pycnometer, Quantachrome Corporation, operating with helium gas (He). The assay was performed at the Laboratory of Synthesis of Ceramic Materials (LabSMaC) of the UFCG.

E. *Viscosity*

For the determination of the viscosity of the cement / hydrogel a viscometer of the Marte brand, model MVD - 5 was used. The instrument is equipped with cylinders of different diameters (spindles), in which the suitable cylinder is used according to the viscosity of the fluid cement. The assay was performed at the Laboratory of Synthesis of Ceramic Materials (LabSMaC) of the UFCG.

F. *Magnetic Measurements*

Using the vibration sample magnetometer (VSM), model 7404 of Lake Shore, the magnetic hysteresis cycles of the samples were obtained. With maximum magnetic field applied 13700 G at room temperature. To obtain the magnetization and magnetic field intensity a Hall effect sensor was used, arranged on an appropriate bench.

III. RESULTS AND DISCUSSIONS

The graphics of the hysteresis curves of the samples under study are shown in Figures 2 and 3. We can observe the behavior of the magnetization (M) as a function of the field (H), through the hysteresis cycle for the hydroxyapatite (HX), synthesized nanoparticulate magnetite (Mag) and same composition with the addition of silylating agents (MagS).

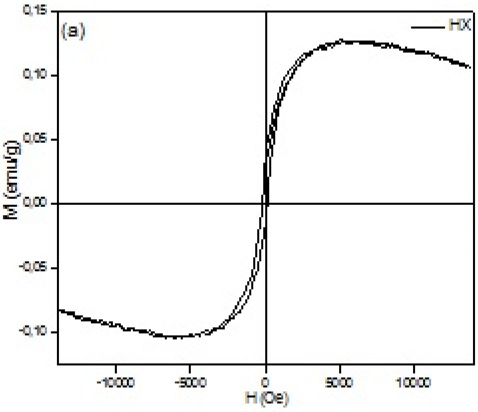

Fig. 2. Hysteresis curves for HX.

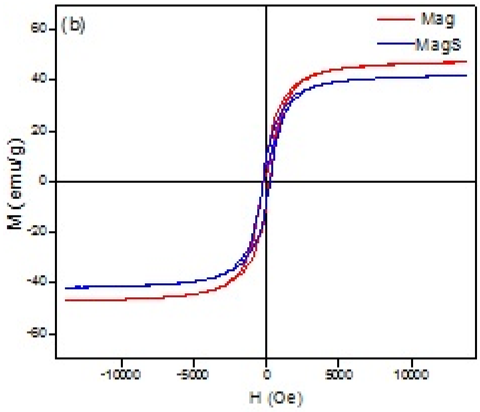

Fig. 3. Hysteresis curves for Mag and MagS.

The MxH cycle presents two simultaneous behaviors, ie, ferromagnetic for the low field (< 5 Oe) and diamagnetic for high field (> 5 Oe) applied [1 Oersted = 79.6 A/m] This behavior is inherent in the chemical composition of HA which is known as a non-magnetic, i.e., diamagnetic oxide.

For magnetite nanoparticles as synthesized and coated with silylating agents, a typical behavior of ferrimagnetic materials can be observed, with the formation of a well-defined hysteresis loop (curve), where the samples have a magnetization of (Ms), a remnant magnetization (Mr) and a coercive field (Hc) (field necessary to demagnetize the material). The study NPMs are a soft material classified as soft mole, in which it magnetizes and demagnetizes with low applied field values, around 258 Oe. After analyzing the behavior of the NPM's in the study after the coating with the silylating agents, it was observed that there was a reduction of the saturation magnetization after the coating of approximately 24.92% when compared to uncoated NPMs, however the ferrimagnetic behavior of the material was maintained.

The results of magnetic measurements for the other samples G1, G2 and G3 (cements) presented a behavior typical of ferrimagnetic materials, with formation of a well defined hysteresis loop and generally have sufficient magnetic properties to show a magnetic response high enough to direct the particles to a specific location in the body.

Figures 3 and 4 shows the graphics with cell viability results for the samples under study. The hydroxyapatite sample (Figure 3a) for its cell viability when exposed to Chinese hamster ovary cells of CHO-K1 strain (ATCC CCL-61), after exposure of the cell population to various concentrations of test substance extract (sample analyzed), hydroxyapatite (HX) is not cytotoxic and cell viability is 89.7%, and its use for the preparation of the samples is feasible and promising [14].

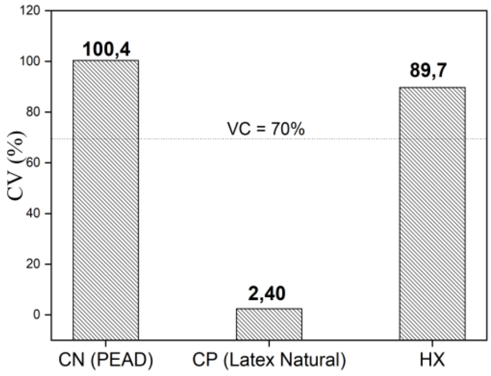

Fig. 3. Cell viability of the reference substances CN (PEAD) and CP (Latex Natural) for the synthesized hydroxyapatite.

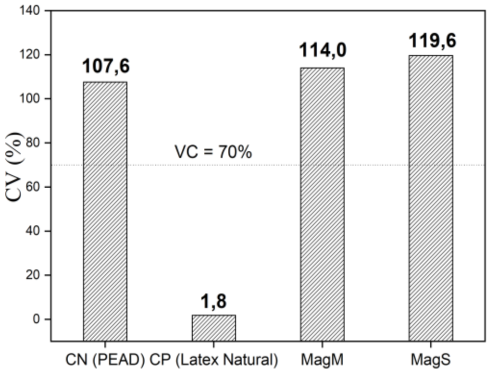

Fig. 4. Cell viability for the magnetic nanoparticles MagM and MagS (with silylanting agentes).

For the cell viability of the magnetite NPMs as synthesize (MagM) and after being coated with the silylanting agentes (MagS) it can be observed that the cell viability was also higher than 70%, so this material being promising for sample preparation. It is noted the coating of the NPMs with the silylanting agents provided and increse in cell viability by aproximately 5% [13].

In Figure 5 are presented images of the cements under study when exposed to drying at room temperature to evaluate the time of handle. It is observed that the cements G1 (Figure 5a) and G2 (Figure 5b) show cracks, characteristic of a dry material, and showed a drying time of 5 and 7 hours respectively. G3 (Figure 5c) cement did not dry in less than 24 hours.

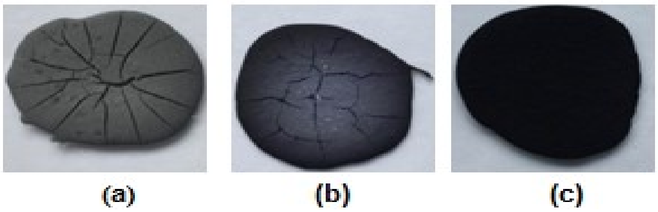
(a) (b) (c)

Fig. 5. Cement in the different mass proportions, (a) G1, (b) G2 and (c) G3, submitted to natural drying.

Three samples of magnetic bone cement were used, in three different mass proportions, synthesized in the LabSMaC. A magnetic field generated by axially magnetized cylindrical neodymium pellets was applied.

It was observed that the smallest magnetic induction value required to promote magnetic fluid movement was 350 mT. Magnetic field values below this had no "pulling force" enough to transpose the cement from one point to another during the tests. Since the magnetic induction of a permanent magnet does not change, a qualitative control of this value was made by varying the distance from the source to the fluid. These values can be observed in Figure 6. In this procedure, up to 10 stacked units of neodymium magnets were used for distances ranging from zero (in contact with the material) to 0.5 cm and the magnetic field was measured using the Hall Effect sensor.

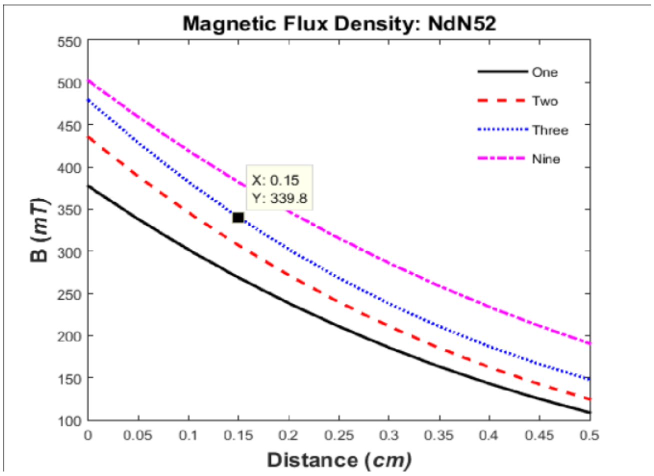

Fig. 6. Magnetic induction.

As expected, the intensity of the field increases as the number of pellets increases, and the same intensity decreases exponentially with increasing application distance. For 1 cm from the sensor, the magnetic field disperses and no longer has sufficient field to attract fluid. Therefore, the use of three superimposed neodymium magnets is sufficient to achieve a magnetic induction of 339.8 mT at approximately 0.15 cm. This distance is not considered sufficient for the application in column surgeries. And although a larger number of overlapping cylindrical inserts can be used, still the use of these magnets is unfeasible for the situation in question. Control and increased induction can be obtained with the use of an electromagnet, which is under construction.

CONCLUSIONS

Magnetic cements presents adequate properties and behavior regarding magnetization, biocompatibility and drying time. It was observed that the cement works for the proposed objective being attracted by the neodymium magnet at 0.15 cm with induction of 339.8 mT. For the desired application it is necessary to increase the magnetization power of the cement or the magnetization power of the magnet. To this end, an electromagnet is being built.

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