

Abstract

Piezoelectric Calcium Modified Barium Titanate for Bone Regeneration [†]

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Abstract: Solid state reaction was used to produced barium titanate modified with calcium (BCT) showing the presence of the piezoelectric tetragonal phase after sintering at 1350 °C. Bioglass 45S5 (BG) was synthesized by sol-gel route. From these two materials and commercial hydroxyapatite (HAp) were obtained composites. The BG produced showed some cytotoxic character that was weakened by passivation. All other materials were non-cytotoxic. Contact polarization at constant temperature was chosen composites polarization. Electric/dielectric properties were evaluated by thermally stimulated depolarization currents (TSDC). The material showed bioactivity with the composite with BCT/BG/HAp 90/5/5 (wt%) showing increased bioactivity. In vitro test showed high proliferation rates for the composites.

Keywords: bone regeneration; piezoelectrics; bioceramics



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1. Introduction

The expanding rate of bone illnesses and fractures has raised an interest in biomaterials applications in hard-tissue engineering [1].

In 1957 was discovered that bone has a piezoelectric character, which plays an important role in bone remodeling [2]. The development of piezoelectrics biomaterials for use in bone regeneration processes can accelerate patient recovery [3].

Barium titanate is a well-known ceramic piezoelectric that is not cytotoxic, but its bioactivity is low. The addition of calcium to BT improves bioactivity. Bioglass is used for bone filling when there is no mechanical load, it has very good bioactivity and biodegradability. On the other hand, hydroxyapatite (HAp) is used in bone remodeling if there are mechanical loads and it is bioactive but has low biodegradability. Also synthetic HAp is similar to the inorganic component of bone. By adding calcium to BT and by producing a composite with BCT, bioglass and/or hydroxyapatite with better properties for applications in bone regeneration.

2. Materials and Methods

Calcium added barium titanate ($\text{Ba}_{0.95}\text{Ca}_{0.05}\text{TiO}_3$) was obtained by solid state reaction. After the BCT was sintered to obtain the piezoelectric tetragonal phase. Bioglass 45S5 (45% SiO_2 –6% P_2O_5 –24.5% CaO –24.5% Na_2O ; wt%) was synthesized by sol-gel. The composites were prepared by adding HAp commercial powders and BG to BCT produced. It was studied 2 different compositions (wt%) BCT/BG/HAp 90/5/5 and 95/2.5/2.5. All

materials were characterized by DTA-TGA, XRD, FTIR, Raman, XRF, SEM/EDS. The cytotoxicity tests in vitro used osteoblastic cells. Samples were polarized by contact at 110 °C and polarization was assessed by TSDC. Bioactivity tests were conducted by immersing the samples in simulated body fluid (SBF) for up to 7 days. Biocompatibility assays were made to evaluate cell adhesion and proliferation.

3. Results and Discussion

For BTC, DTA-TGA allowed to optimize the sintering temperature that guarantees the presence of the tetragonal phase. The diffractograms obtained showed the characteristic duplet around 45°. FTIR, Raman and SEM/EDS allowed further confirmation of the tetragonality of BTC but also detected some cubic phase. BG composition was determined using fluorescence spectroscopy and the results confirmed a composition close the theoretical one. Initially the BG was cytotoxic, but it was possible to decrease this characteristic by passivation. In spite of that, the composites were non-cytotoxic because the amount of BG was kept low enough.

Electrical polarization of the composites was successful and this was shown by TSDC, total charge was of the order of 10^{-5} C, with a higher value when a positive field was applied. Using SEM/EDS it was possible to observe that all samples of the composites showed some bioactivity in spite that there was some loss of tetragonality. The highest value was obtained for 90/5/5 and for the surface that was positive (see Figure 1).

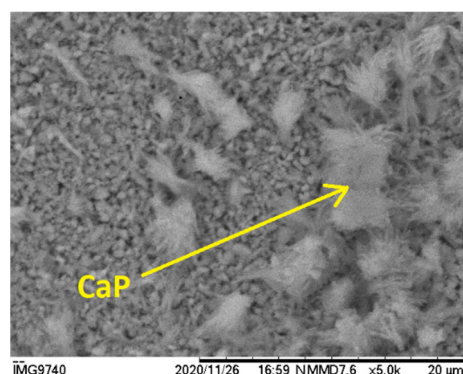


Figure 1. SEM image of the positive surface of the BTC/BG/HAp composite presenting the formation of apatitic crystals (CaP). The yellow arrow point to one of the CaP crystals.

Cell adhesion lowers considerable in the composites compared with the BCT samples. Probably this is due to BG ionic exchanges that alter the medium pH. For the proliferation promising results were obtained, with higher values for both composites when compared with BCT.

4. Conclusions

The produced composites have a high proliferation rate and a higher bioactivity, mainly on the positive charged surfaces, even if their processing modified the material structure, reducing the tetragonal character.

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References

1. Kandula, H.; Darandale, M.; Sumant, O. Orthopedic Implants Market In-Depth Analysis | Forecast—2030. Available online: <https://www.alliedmarketresearch.com/orthopedic-implants-market> (accessed on 28 February 2022).
2. Fukada, E.; Yasuda, I. On the Piezoelectric Effect of Bone. *J. Phys. Soc. Jpn.* **1957**, *12*, 1158–1162. [[CrossRef](#)]
3. Khare, D.; Basu, B.; Dubey, A.K. Electrical stimulation and piezoelectric biomaterials for bone tissue engineering applications. *Biomaterials* **2020**, *258*, 120280. [[CrossRef](#)] [[PubMed](#)]