Nanoelectronics Undergraduate Research Fellowship (NURF)
2010 Project Summary

Student name: He Zhao
Faculty mentor name: Dr. Abhijit Biswas
Project title: Design, Synthesis and Characterization of All-Bone Minerals Multicomponent Bionanocomposites for Bone Grafts Using Bone-Tissue Engineering

Problem / problem area

Bone is a specialized form of connective tissue that forms the skeleton of the body. It is a composite material consisting of a hard inorganic phase (minerals) in an elastic, dense organic gel network. The key bone minerals and chemical elements are hydroxylapatite (HA), collagen protein fibers, phosphorus and calcium. This combination of inorganic and organic phases not only provides bone with unique mechanical properties and a reservoir for minerals such as calcium and phosphate but also serves as a medium for diffusion and release of biological substances. Despite the fact that bone is the strongest tissue in the body and has the capability of self-regenerating, it often undergoes damage or defect caused by some form of bone disease and/or bone injury. Bone grafting is commonly employed to treat bone defect. The key functions of bone grafts are to provide mechanical or structural support, fill defective gaps and enhance bone tissue formations. The ultimate goal of bone grafting is the restoration of bone defects by the regeneration of living tissues. The conventional procedure for bone grafting is to procure bone tissues from the healthy donor site and re-implant at the locations where the bone replacement or reconstruction is required. However, such a natural grafting process has limitations due to several factors such as the possibility of pathogen transfer, graft rejection and limited available bone tissue etc. Therefore, it is of immense interest to develop artificial biomimetic and biocompatible bone materials that can be employed for bone grafting or implantation purposes.

Activities & Results

Bionanocomposites are promising new artificial bone materials that use a combination of several biocompatible materials and bone minerals and structurally tuned to resemble the natural bone structure. These nanocomposites offer larger surface area, high surface reactivity, relatively strong interfacial-bonding, design flexibility and enhanced mechanical properties than conventional bulk composites. They offer the possibility of creating true bone grafts using bone tissue engineering that involves the effective applications of cells, scaffold and cell-scaffold interaction. It is highly desired that bionanocomposites are suitably designed and synthesized that have all the important bone minerals that are grown in intimate contact with a biocompatible organic matrix rich in collagen (protein) fibers. In this NURF project, we successfully developed a low-cost, facile method for large-scale synthesis of novel all-bone-minerals multicomponent bionanocomposites. Figure 1 schematically illustrates the synthesis route (a) and a picture of bionanocomposite material (b).

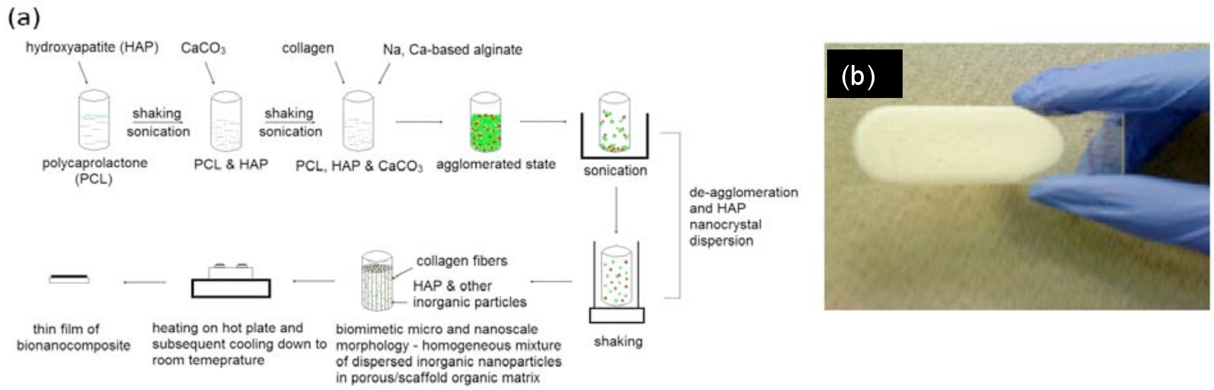
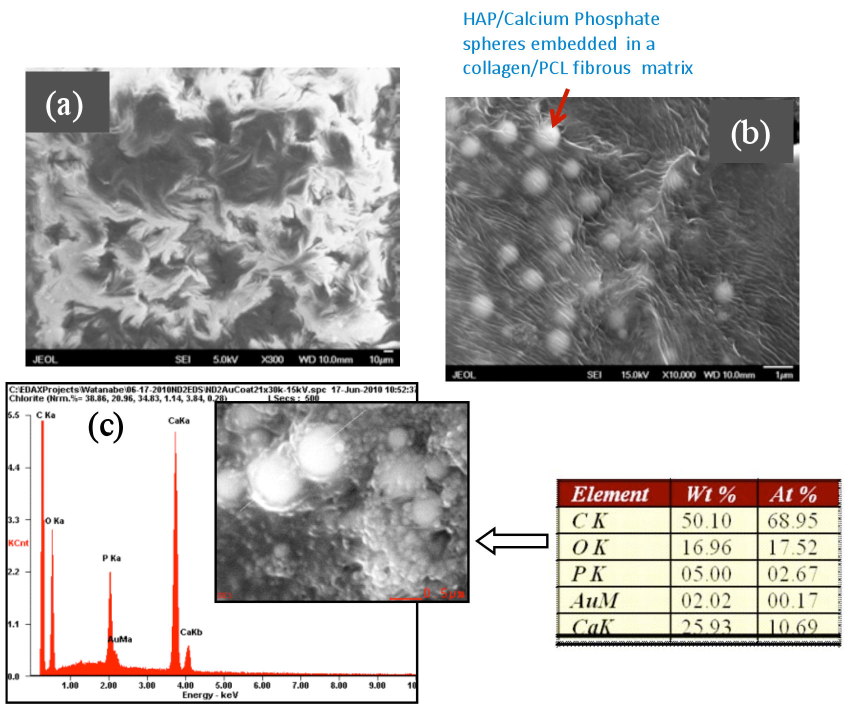


Figure 1: (a) Schematic illustration of the synthesis process of bionanocomposite. (b) A picture of bionanocomposite bone material in solid state.



Element	*Wt %*	*At %*
C K	50.10	68.95
O K	16.96	17.52
P K	05.00	02.67
AuM	02.02	00.17
CaK	25.93	10.69

Figure 2: (a) A scanning electron microscope (SEM) overview image of scaffold structure of bionanocomposite consists of Polycaprolactone (PCL), Hydroxyapatite (HAP), Calcium Carbonate ($CaCO_3$), Collagen, Calcium and Sodium based Alginate. (b) Higher magnified SEM image of HAP spheres embedded in collagen rich fibrous matrix. (c) Energy Dispersive X-ray (EDX) analysis of bionanocomposites and the corresponding elemental compositions are shown in the table. EDX measurements show an oxygen-rich bionanocomposite system.

We achieved the important structural control to produce the required three dimensional scaffold structures (Figure 2a) along with appropriate surface roughness and combination of micro and nanoscale features that are required to match the natural bone structures. The tailoring of the structure resulted in collagen-rich fibrous matrix (Figure 2b), which is highly desired for tissue generation. Collagen is a protein and one of the most important bone minerals found in human bone and responsible for bone growth. One of the major problems in current state-of-the-art implants is the low oxygen supply, which causes bone cells to die prematurely. The cells of bone receive oxygen from limited sources (the nutrient artery being the major source). Hence, it is very important that the biomaterials have sufficiently high elemental oxygen that can help maintain revascularization for nutrient and compensate for loss of oxygen supply to the cells. We addressed this issue and successfully controlled the nanophase compositions of the bone minerals in the bionanocomposites to have very high oxygen content in the material system (Figure 2c). The EDX analysis of the control sample (only polymer, PCL) did not show presence of oxygen, calcium or phosphorus. Varying the compositional ratio of $CaCO_3$ and HAP allowed to vary the atomic percentage of oxygen in the bionanocomposites. Further studies on human bone marrow stem-cell culture analysis of the synthesized bionanocomposites are underway.

Acknowledgement

The NURF fellowship is gratefully acknowledged.

List of papers / posters

[1] A manuscript is under preparation based on the preliminary data, to be submitted.

[2] He Zhao, Abhijit Biswas, Gary Bernstein and Wolfgang Porod, *Design and Fabrication of Nanocomposites for Advanced Technology Applications,* poster presented at the conference "Towards Regulation of Nanomaterials", University of Notre Dame (May 10-12, 2010).

[3] He Zhao, Abhijit Biswas, Gary Bernstein and Wolfgang Porod, *Design, Synthesis and Characterization of All-Bone Minerals Multicomponent Bionanocomposites for Bone Grafts Using Bone-Tissue Engineering,* posters to be presented at the ND Science and Engineering Summer Research Symposium - August 6, 2010, and MIND Annual Workshop, University of Notre Dame, August 10, 2010.