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**METHOD AND APPARATUS FOR
ENGINEERED REGENERATIVE
BIOSTRUCTURES SUCH AS
HYDROXYAPATITE SUBSTRATES FOR
BONE HEALING APPLICATIONS**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 60/283,564 filed Apr. 12, 2001.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to engineered regenerative biostructures, and more particularly to porous bone augmentation articles with microporosity, mesoporosity and/or macrochannels and other osteoconductive features and other materials.

2. Description of the Related Art

It is currently of great interest to identify and exploit what features of implantable materials are conducive to in-growth of new bone. Bone response to grafting materials depends on a complex interaction between the chemical composition of the material, surface texture, pore size and porosity, implant geometry, and degradation products. Grafting alternatives have included: autogenous or autograft bone (bone harvested from another site within the patient); allografts (bone harvested from a cadaver); and a range of synthetic scaffolds materials. Synthetic scaffolds materials have included: coralline hydroxyapatite; mixtures of hydroxyapatite, tricalcium phosphate, and bovine collagen; human demineralized bone and glycerol; and calcium sulfate pellets. Such compounds are osteoconductive and in some cases resorbable.

Most of the literature on bone in-growth has taught that pore size should be at least 100 microns in order to promote bone in-growth. All of these products have limitations. Human-derived materials depend on availability of suitable donors. Within any given sample, naturally occurring materials and their derivatives have large variations in both porosity and permeability. Degradation products of some classes of material can activate inflammatory responses. Matching porosity and internal architecture to specific tissue response remains an unmet challenge.

PLA and PGA have been used in synthetic bone implants. PLA and PGA were less than ideal for tissue-engineered scaffolds for bone healing applications, especially in areas of low vasculature, where degradation products could not be quickly eliminated from the implant site. PLA and PGA released acidic degradation products, often causing newly formed bone in those areas to be resorbed. Further, microcrystalline particulate debris, created during the resorption/breakdown process, has been implicated in stimulating a significant inflammatory response, especially with long-term implants.

In other applications, hydroxyapatite (HA) has been used in either granular form or block form. Several challenges exist with using HA in this form. It has been difficult to shape blocks of HA. The particulate form of the material has been used to shape or conform to the geometry of a surgical site, thus eliminating the shaping problem, but. The particulates often migrate, resulting in voids and associated vulnerability to inflammation within the surgical site. Furthermore, fully dense HA has produced disappointing results in bone implants largely since it can only become fixed to the bone via surface attachment.

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BRIEF SUMMARY OF THE INVENTION

The present invention overcomes the limitations of the prior art and provides additional benefits. Under one aspect of the invention, an engineered regenerative biostructure (ERB) includes an internal microstructure, mesostructure and/or macrostructure. Under another aspect of the invention, the biostructure comprises Hydroxyapatite. Under another aspect of the invention, the biostructure has resorbable and nonresorbable regions. Under yet another aspect of the invention, the biostructure comprises demineralized bone matrix. Under yet another aspect of the invention, the porous biostructure is partially or fully infused with one or more substances or categories of substances. The invention also includes associated manufacturing methods for all of these aspects.

BRIEF DESCRIPTION OF THE SEVERAL
VIEWS OF THE DRAWINGS

The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawings(s) will be provided by the Office upon request and payment of the necessary fee.

FIG. 1 illustrates an isometric view of a three-dimensional printing apparatus in accordance with the prior art.

FIGS. 2A, 2B and 2C are one embodiment of an engineered regenerative biostructure in accordance with principles of the present invention.

FIG. 3 is a partial cross sectional view of the macrostructure and mesostructure of the engineered regenerative biostructure of FIG. 2 taken along line 3—3 in accordance with principles of the present invention.

FIG. 4 is an enlarged cross sectional view of the mesostructure of FIG. 3 taken along line 4—4 in accordance with principles of the present invention.

FIG. 5 is an isometric view of a mesostructure in accordance with principles of the present invention.

FIG. 6 is an isometric view of a printhead, binder droplet and powder layer in accordance with principles of the present invention.

FIGS. 7A—7D are a schematic illustration of process steps for forming a macrostructure in an engineered regenerative biostructure in accordance with principles of the present invention.

FIGS. 8A—8D are a schematic illustration of process steps for forming a mesostructure in an engineered regenerative biostructure in accordance with principles of the present invention.

FIGS. 9A and 9B are isometric views of an engineered regenerative biostructure with mesostructure in accordance with principles of the present invention.

FIG. 10 is a schematic view of a stacked binder deposition configuration in accordance with principles of the present invention.

FIG. 11 is a schematic view of a staggered binder deposition configuration in accordance with principles of the present invention.

FIG. 12 is an exploded schematic view illustrating the relevant elements for slurry printing through single nozzle with switching in accordance with principles of the present invention.

FIG. 13A is an isometric view of a three-dimensional printing apparatus configured for suspension deposition with two co-aimed dispensers in accordance with principles of the present invention.