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Review

Development of nanocomposites for bone grafting

R. Murugan *, S. Ramakrishna *

NUS Nanoscience and Nanotechnology Initiative (NUSNNI), Division of Bioengineering, Faculty of Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore

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Abstract

This article reviews nanocomposites focusing on their impact and recent trends in the field of bone grafting. Although autogenous- and allogeneic-bone grafts have been used for a long time in bone therapies, there is still a donor shortage and infection risk. As an alternative, synthetic biomaterials have been developed and clinically used as bone grafts, but most of them differ substantially from natural bone either compositionally or structurally. It remains a great challenge to design an ideal bone graft that emulates nature's own structure. Owing to the composition and structural similarity to natural bone, most of the current investigations involve the use of nanocomposites, particularly hydroxyapatite/collagen system, as promising bone grafts, but it is surprising that none of the reports review the rationale and design strategy of such nanocomposites in detail for the benefit of researchers. Accordingly, this article addresses the state-of-the-art of those nanocomposites and provides suggestions for future research and development. This review provides an overview of the nanocomposite strategy of bone, bone grafting, synthetic approaches to bone structure, development of nanocomposites from the conventional monolithic biomaterials, and recently developed processing conditions for making nanocomposites. The review is expected to be useful for readers to gain an in-sight on the state-of-the-art of nanocomposites as a new class of synthetic bone grafts.

Keywords: Hydroxyapatite; Collagen; Bone; Nanocomposites; Biomechanics; Biomimetics; Tissue engineering; Bone grafting

Contents

* Corresponding authors. Tel.: +65 6874 6593; fax: +65 6874 3346.
E-mail addresses: engmr@nus.edu.sg (R. Murugan), seeram@nus.edu.sg (S. Ramakrishna).

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1. Introduction

Bone is an amazing and a true nanocomposite. It is a complex and a highly specialized form of connective tissue pertaining to the formation of the skeleton of the body. Bone, not only provides mechanical support but also elegantly serves as a reservoir for minerals, particularly calcium and phosphate. It is a good example of a dynamic tissue, since it has a unique capability of self-regenerating or self-remodeling to a certain extent throughout the life without leaving a scar [1]. However, many circumstances call for bone grafting owing to bone defects either from traumatic or from non-traumatic destruction. With reference to statistical reports [2–4], about 6.3 million fractures occur every year in the United States of America (USA) itself, of which about 550,000 cases require some kind of bone grafting. It was also noticed that the fractures occur at an annual rate of 2.4 per 100 population in which men seem to experience more fractures (2.8 per 100 population) than women (2.0 per 100 population). The most frequently occurring fractures are, in decreasing order, hip, ankle, tibia, and fibula fractures. It is reported that the total number of hip replacements was about 152,000 in the year 2000, which is an increase of about 33% compared to the year 1990 in the USA alone and it is expected to increase to about 272,000 by the year 2030 [5], indicating that there is still a great need for synthetic bone grafts. According to a market survey conducted by Medtech Insight [6], bone grafts sales was found to exceed US$980 million in 2001 in the USA and about US$1.16 billion in 2002, which is also expected to double by 2006. In Europe, the number of bone grafting procedures was reported to be 287,300 in 2000 and it is expected that it could be increased to about 479,079 in 2005 [7]. In 2000, the worldwide use of bone grafts was estimated to be about 1 million, of which about 15% of the surgery had used synthetic bone grafts. It was also suggested that the future growth largely attributes to tissue-engineered composites, i.e., composites containing osteogenic cells and growth factors.

The need for synthetic bone grafts depends on the complication of the bone defects. For example, if the defect is minor, bone has its own capability to self-regenerate within a few weeks. Therefore, surgery is not required. In the case of severe defects and loss of volume, bone would not heal by itself and grafting is required to restore function without damaging living tissues. There are multiple methods available for the treatment of bone defects, which includes the traditional methods of autografting and allografting. Although autografting and allografting are clinically considered as good therapies, they have limitations. For example, supply of autograft is limited and there is a possibility of pathogen transfer from allograft. Accordingly, there is a great need for the use of synthetic bone grafts. Nowadays, numerous synthetic bone graft materials, both single- and multi-phases, are available which are capable of alleviating some of the practical complications associated with the autogenous or allogeneic bones. Although there is good progress in bone grafting using synthetic bone grafts, the way in which they execute their functions in vivo is quite different and most of them differ from natural bone either compositionally or structurally. Further, a single-phase material (also called monolithic) does not always provide all the essential features required for bone growth, which leads to incessant investigation in search of an ideal bone graft. There is, therefore, a great need for engineering multi-phase materials (also called composite) with structure and composition similar to natural bone. Recently, nanocomposites, particularly hydroxyapatite (HA)- and collagen-based, have gained much recognition as bone grafts not only due to their composition and structural similarity with natural bone but also because of their unique functional properties such as larger surface area and superior mechanical strength than their single-phase constituents. Further, natural bone itself is a nanocomposite matrix composed mainly of HA nanocrystallites in the collagen-rich organic matrix [8,9]; thereby choosing a HA/collagen nanocomposite as a bone graft material is an added advantage. An extensive and informative review on HA-based biomaterials has suggested that the HA/collagen composite is probably the most suitable system for bone replacement or regenerative therapy [10].

This article emphasizes the importance of HA/collagen nanocomposites in bone grafting. It also discusses some of the critical issues and scientific challenges that might be needed for further research and development.