1 Stem Cells and Nanostructured Materials

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Abstract Stem cells and nanomaterials are currently two of the most promising technologies for tissue regeneration and the treatment of degenerative disease. Because of their ability to self-renew and differentiate into any cell type, stem cells offer the potential to regrow all types of damaged or degenerated tissues that are unrepairable by currently available treatment methods. Nanomaterials may prove to be ideal growth substrates for tissue regeneration as well as an ideal delivery vehicle for the diagnostic markers, growth factors, and drugs that are required to promote tissue regeneration and treat degenerative disease. Despite their great potential, stem cell behaviors such as proliferation and differentiation must be tightly regulated in order for this technology to be practical in a clinical setting. Experimental evidence has shown that the interactions of nanomaterials with stem cells can have a significant effect on many types of stem cell behaviors. In addition, nanomaterials can be used to provide targeted delivery of various agents in a controlled manner that allows for regulation of the chemical environment. Regulation of the chemical environment is critical for controlled guidance of stem cell behavior and for the treatment of degenerative disease. A precise understanding of the interactions between stem cells and nanomaterials is an important step toward unlocking the great potential of these two technologies.

Keywords nano, stem cell

1.1 Introduction

Stem cells and nanotechnology, two exciting and rapidly growing fields, have received extensive attention during the last decades. Stem cells and precursors
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bring new hope to regenerate functional tissue with native histological structures and properties, as opposed to simple replacement with artificial structures alone. The two main advantages of stem cells are the ability to self-renew, which means they can reproduce themselves, and the ability to potentially differentiate into all the possible cell types (Pedersen, 1999; Solter and Gearhart, 1999). Stem cells may be harvested from two different sources. Embryonic stem (ES) cells may be harvested from embryos and can be derived from germ cells as well. If problems such as immune rejection and the high possibility of tumorigenicity can be solved, ES cells may serve as a good source of cells for tissue regeneration. Their potential for the study of human developmental biology is always promising (Good, 1998). Stem cells can also be harvested from adult tissue, such as from muscle, cartilage, bone, nervous system, liver, pancreas, tooth, adipose tissue, etc. (Good, 1998). Like stem cells, precursor cells can differentiate into more than one cell type, but these cells have undergone some degree of differentiation (Weissman, 2000). For example, glial-restricted precursors (GRP) can differentiate into type I and type II astrocytes and oligodendrocytes, but not neurons (Foster and Stringer, 1999). Precursor cells can be harvested from adult tissue as well (Rizzoli and Carlo-Stella, 1997). Knowledge of stem cells can also bring profound insight to cancer research due to the fact that many cancer cells possess the characteristics of stem/progenitor cells and many cancer cells originated from stem cells. It is known that two key chemical signals, Hedgehog and Wnt, are active in the stem cells that repair damaged tissue. These signals also have been found in certain hard to treat cancers, supporting an old idea that some cancers may start from normal stem cells that have somehow gone bad. Therefore, a section about cancer treatment using nanostructured biomaterials is included in this chapter as well.

Nanostructured materials refer to certain materials with delicate structures of ‘small’ sizes, falling in the 1 – 100 nm range, and specific properties and functions related to the ‘size effect’ (Niemeyer, 2001; Safarik and Safarikova, 2002; Whitesides, 2003). Dramatic development of nanotechnology in material science and engineering has taken place in the last decade (Gao et al., 2004; Niemeyer, 2001; Whitesides, 2003). This does not come as a surprise considering that nanostructured materials have the capability to be adapted and integrated into biomedical devices, since most biological systems, including viruses and membrane and protein complex, are natural nanostructures (Laval et al., 1999). Currently, medicine and biomedical engineering are among the most promising and challenging fields involved in the application of nanostructured materials (Desai, 2000; Ziener et al., 2005). Rapid advancements of nanostructured materials have been made in a wide variety of biomedical applications, including novel tissue engineered scaffolds and devices, site-specific drug delivery systems, non-viral gene carriers, biosensor and screening systems, and clinical bio-analytical diagnostics and therapeutics (Mazzola, 2003; Ziener et al., 2005). For example, nanocomposites have been used to stabilize and regenerate bone matrices (Bradt