CHAPTER 1

Introduction

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Bionanotechnology strives to fabricate functional biohybrid structures by synergistically combining biomacromolecules, cells, or multicellular assemblies with a wide range of nanomaterials, to which interesting functionalities are deliberately designed and introduced at the nanometer scale. The equipment of micrometer-sized cells with tiny devices, expanding the uses of the cells in biotechnology and biomedicine, also requires the nanoengineering of individual cells. Cells, having the typical sizes of dozens of micrometers, are relatively large if compared with nanometer-sized particles and films; therefore, the nanomodification of living cells opens new pathways to perform the selective control of cell properties. One can dream of designing a comfortable ‘‘smart dress’’ for cells, which protects the cells from hostile external environments and also provides useful toolkits that the cells may learn to use for their benefit. In addition to the application aspect, the ‘‘smart dress’’ coatings can be applied to the detailed investigation of fundamental biological properties, such as enzyme activity, membrane permeability, or viability preservation in cells, among many others.

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The recent progress in bionanotechnology has been based extensively on inspiration from nature and adopted the mechanisms and structures found in living creatures for elaboration of man-made materials and devices. The cells are the biological units, which are used by nature to build all known living organisms, from micro-organisms to human beings.[1] The complexity of cellular machinery, consisting of precisely orchestrated ensembles of enzymes, nucleic acids, and other biological macromolecules, is yet to be understood. However, each and every cell has a *cellular membrane*, acting as the thin barrier that protects the cell from the outer environments, ensures the internal integrity, and facilitates the controllable transport of the chemical species and particles. The cellular membranes are as diverse as the cells themselves, displaying a number of surface molecules, which can be used as a fingerprint profile of a certain biological species. Generally, they are built of membrane proteins, lipids and carbohydrates, complementing one another to support the shape, integrity and functionality of the cells. In addition to lipid bilayer membranes, some cells (*i.e.* most of bacteria, fungi, and plants) develop a thick protective coating, termed the *cell wall*, which reinforces the membranes and makes the cell-wall-protected cell rigid and resistant to external impacts. Other species rely solely on subtle cellular membranes, while sometimes employing exoskeleton-like structures like solid shells or building external skin-like structures. The enormous number of biological events is associated with the surfaces of membranes and cell walls, which are responsible for ion pumps, feeding, excretion, neurotransmission, antibody/antigen recognition, cell division, *etc.* Virtually all of the cellular processes are controlled or regulated directly or indirectly by cellular surfaces that interface with the outer surroundings. Here, we regard all the cellular coatings as external *cell surfaces*, which exhibit certain surface chemistries. Like biological systems, any changes in cell-surface chemistry will inevitably lead to changes in cell functioning, and provide the cells with otherwise unavailable functionalities. Recent progresses allow for modification/functionalization of biological cells, viewed as colloid microparticles (albeit their very complex nature) in the first approximation, with the wide range of chemical techniques in a controllable fashion.

In this book, we define *cell surface engineering* as a chemical methodology aimed to deliberately modify, control, functionalize or alter the nanoscale surface chemistry of biological cells by the directed deposition of macromolecules or nanomaterials as artificial shells on the nanometer scale.[2] The ultimate goal of the cell surface engineering is to fabricate an artificial nanocoating on the cellular surfaces without modifying the genome of the cells by using purely chemical architecture approaches. The cell nanocoating generates various types of artificial cell-in-shell structures, where single isolated cells or cell aggregates are coated with either flexible or solid shells. These shells are typically fabricated to endow the cells with additional functionalities of interest. Alternatively, the cells can be used as mere sacrificial templates for fabrication of cell-mimicking hollow microcapsules or as parts of microelectronic devices. Historically, the layer-by-layer (LbL)[3] deposition technique was used first to form nanolayers over sacrificial cells, but in the recent decade, a number of other approaches have emerged, offering new avenues in cell surface engineering.

We start this book with the introduction of three most popular approaches in cell surface engineering: 1) multilayered polyelectrolyte assemblies; 2) direct deposition of nanomaterials, and 3) bioinspired encapsulation with inorganic shells. These approaches have been successfully applied to fabricate nanocoatings on numerous representative model organisms. Next, the book reviews the experimental techniques to characterize and image the nanomaterial-encapsulated cells and to assess the viability and biological functionality of the surface-engineered cells. Then, we focus on applications of the nanocoated cells. The topics include the microelectronic devices fabricated with nanocoated cells including magnetically labeled prokaryotic and eukaryotic cells in analytical applications, and the LbL-coated cells in biomedical applications, such as tissue engineering and biosensors. Finally, the book covers the fabrication of artificial multicellular assemblies, where cells interfaced with polymers and nanomaterials are used as building blocks, and the formation of artificial spores mimicking bacterial endospores. These areas are truly multidisciplinary, utilizing the practical skills in nano- and colloidal sciences to chemically mimic and control biological processes, such as of evolution of multicellularity and cryptobiosis.

References

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