3D integrated bionanotechnology: From bionic devices to untethered surgical tools

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Abstract

An important challenge of nanotechnology is to integrate physical processes and human engineered devices with biological cells and organisms. Human engineered devices can facilitate communication, logic and memory processing while biological devices are self-propelled, adaptive and environmentally responsive. Hence, combining these attractive features and facilitating mechanisms to bridge the divide between the two worlds could significantly augment the capabilities of human engineering and also provide new strategies for medical diagnostics and therapeutics.

However, bridging the divide between the engineered and biological worlds is very challenging. Firstly, there is an inherent mismatch in the processes used to create electronic devices and biological systems. Most processes such as thin film deposition in electronic fabrication are vacuum based processes and many of the devices are incompatible with aqueous media. Further, physical devices are often mechanically rigid while biological devices are often soft and squishy. Finally, many functional micro and nanoscale devices are produced by inherently planar lithographic or serial approaches while biological cells and organisms are truly 3D and self-organize in large numbers.

In an attempt to tackle these challenges, I will highlight by way of examples, two strategies that merge concepts, processes and/or functionalities from the engineering and biological worlds at small size scales.

Firstly, I will discuss how functionalized nanoparticles can be attached to the surfaces of microorganisms such as bacteria to alter the behavior of these microorganisms. Importantly, nanoparticles can be grown or self-assembled in large numbers so that bacterial hybrids can be formed using solution based antibody-linking schemes.[1] I will further illustrate how such bionic nano-particle bacteria hybrids can be used to ferry cargo and transmit signals between the external physical and biological worlds. In addition, I will also discuss the creation of bionic organs via 3D printing of nanoparticles and cells to form ear-like devices with embedded antennas.[2]

Secondly, I will discuss the creation of large numbers of sub-mm and even single cell sized devices for medicine. These include biodegradable surgical microdevices and mechanical traps for single cell capture and analysis.[3] Additionally, I will also discuss the design and operation of dust-sized biopsy forceps to perform the first ever *in-vivo* biopsies[4] illustrating that the development and safe deployment of mass-producible untethered surgical tools could make surgery more effective and less invasive.

Representative references: [1]R. Fernandes et al, Small 7, 5, 588-592 (2011). [2]M. S. Mannoor, et al, Nano Letters, 13, 6, 2634–2639 (2013). [3] K. Malachowski et al, Nano Letters 14, 7, 4164-4170 (2014). [4]E. Gultepe, et al, Advanced Materials 25, 4, 514-519 (2013).