Hydrogels as Biomaterials: Infinite Possibilities in Bionanotechnology, Drug Delivery, Biological Recognition, Tissue Engineering, and Pure Scientific Fun!

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Over the past 35 years, hydrogels have been approved as biomaterials in a wide range of biomedical applications and devices. Extensive studies of their biocompatibility have been reported. Hydrogels have functional groups along the polymer chain that react to the external environment (e.g. temperature, ionic strength, and pH of the swelling agent).

In recent years, there has been considerable work in preparing intelligent hydrogels and finding new uses for nanoscale structures based on biomaterials. Uses such as carriers for controlled and targeted drug delivery, micropatterned devices, systems for biological recognition, have shown the versatility of these biopolymeric materials.

Of specific interest are applications requiring the patterning of vinyls, methacrylates and acrylates during reaction allowing for the formation of nanoscale three-dimensional structures. These micropatterned structures may be used for a host of applications including cell adhesion, separation processes, the so called “factory-on-a-chip” microscale reactors, and microfluidic devices.

Why do we observe such explosion in the field now? Electronic devices have now reached a stage of dimensions comparable to those of biological macromolecules. This raises exciting possibilities for combining microelectronics and biotechnology to develop new technologies with unprecedented power and versatility. While molecular electronics use the unique self-assembly, switching and dynamic capabilities of molecules to miniaturize electronic devices, nanoscale biosystems use the power of microelectronics to design ultrafast/ultrasmall biocompatible devices, including implants, that can revolutionize the field of bioengineering.

Thus, in recent years we have seen an explosion in the field of novel microfabricated and nanofabricated devices using intelligent hydrogels. Such devices seek to develop a platform of well controlled functions in the micro- or nano-level. They include nanoparticulate systems, recognition molecular systems, biosensing devices, and microfabricated and microelectronic devices.

For example, polymer surfaces in contact with biological fluids, cells, or cellular components can be tailored to provide specific recognition properties or to resist binding depending on the intended application and environment. Engineering the molecular design of biomaterials by controlling recognition and specificity is the first step in coordinating and duplicating complex biological and physiological processes. The design of surfaces for cellular recognition and adhesion, analyte recognition, and surface passivity encompasses a number of techniques such as surface grafting (ultraviolet radiation, ionizing radiation, electron beam irradiation). Certain techniques can change the chemical nature of surfaces and produce areas of differing chemistry as well as surfaces and polymer matrices with binding regimes for a given analyte.

In addition, biomimetic methods are now used to build biohybrid systems or even biomimetic materials (mimicking biological recognition) for drug delivery, drug targeting, and tissue engineering devices. The synthesis and characterization of biomimetic gels and molecularly imprinted drug release and protein delivery systems is a significant focus of recent research. Configurational biomimetic imprinting of an important analyte on an intelligent gel leads to preparation of new biomaterials that not only recognize the analyte but also act therapeutically by locally or systemically releasing an appropriate drug.