Biomimetic Smart Polymer Materials

Dr. Thilini Kuruwita Mudiyanselage

Senior Lecturer, Department of Chemistry, University of Sri Jayewardenepura

Five decades ago, polymers were just plastic and rubber that were limited mostly to day to day household applications such as car tyres, slippers, cups, plates, etc. We simply would not able to persist today even a day without using any polymeric material. Whether we accept it or not, the reality is that we live in an era of polymers. With the development of material sciences, polymeric materials have invaded our lives to each and every corner. It varies from simple house holding items like plastic spoons and rubber rugs to sophisticated applications like smart phones, flat screen televisions and even in rockets and satellite. Over the years, polymers have merged to the area of medicine strongly and steadily. Early days polymers in medicine were just limited to very simple materials like gloves, syringes, tubes, etc.

One such application is "Smart Polymers". The family of smart polymers is quite wide with many different substances. Common features of smart polymers are that one or more properties of the polymer may rapidly change, in a reversible and repeatable manner with respect to external stimuli. Simply, a polymer that can respond in any useful manner to any stimuli may categorized under this classification. The stimuli could be light, temperature, pressure, pH, electric and magnetic fields, chemicals, or even nuclear radiation. The correlated response could be changeable physical properties such as color, shape, stiffness, or viscosity. Since these polymers display adaptive capabilities to the environment they are also entitled the term intelligent polymers.

Artificial Muscles

Any living organism responds to external stimuli and amend themselves accordingly. As an example, we, humans respond to five external stimuli such as image, sounds, smell, flavors and touch. It is an enormous challenge to mimic the behavior of a living organism, and scientists were struggling to conquer this dream of artificial intelligence over many decades (Figure 1). Smart polymers/materials have paved a positive path for scientist to achieve this once unreachable challenge. Development of artificial muscles is one such marvelous endeavor reported in literature.

Figure 1: Imaginary drawings of artificial intelligence

Human muscles convert chemical energy to mechanical energy and heat at body temperature. This process happens in aqueous media and the involved steps are: a) Pulse generation in the brain, b) an electric pulse (ionic) arriving from the brain through the nervous system, c) liberation of calcium ions inside the sarcomere, d) chemical reactions (ATP hydrolysis), e) conformational changes along natural polymeric chains (actin and myosin) with change of the sarcomere volume, and f) water exchange (Figure 2). Thus, smart polymers that respond by changing shape or size to external stimuli could lead to the development of artificial muscles. Electrical stimulus is the commonly reported trigger in literature and is the most promising approach to mimic organisms. Conducting polymers (CP) are of the highest interest on this regard. One promising approach is to develop triple CP/tape/CP layer from two CP films sandwiching a stainless-steel electrode. When applying a constant current, one CP acts as the anode; thus, it gets oxidized and swells, while the other acts as the cathode; polymer reduces and shrinks (Figure 3). Such volume variations make the device bend and when a current is applied in the opposite direction, the device displays opposite movements, that means a controlled movement to an electrical pulse; thus, functions as an artificial muscle!

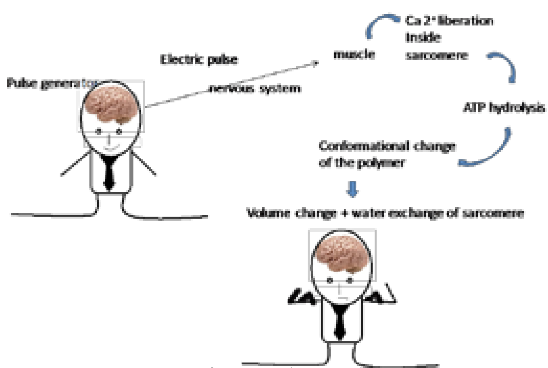

Figure 2: Function of natural muscle

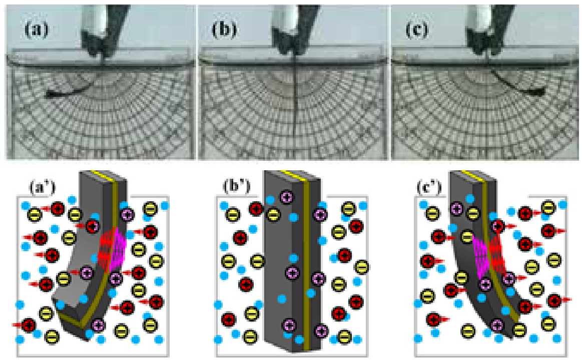

Figure 3: Pictures showing the bending movement during the flow of a direct current: the sense of the movement is reversed by changing the sense of the current flow.

Drug Delivery Systems

Drug delivery is the method, process, approach, formulation, technology, and system of dispensing a pharmaceutical compound (drug) to achieve a therapeutic effect in humans or animals. Drug must be applied to the right area, at the right time and at the right concentration. Smart polymers have invaded this art of science due to promising features like releasing the drug at the biological demand and operating fully autonomously. Applied stimuli reported in literature are temperature, electric current, pH *etc*.

One simple example is entrapping an active drug in a smart hydrogel which responds to pH. At a change of the environment (pH change), the smart hydrogel responds mechanically by either swelling or shrinking (Figure 4). This mechanical change of the gel helps the trapped active ingredient to be released in a controllable manner since diffusion of the drug out of the hydrogel depends on the state of the gel.

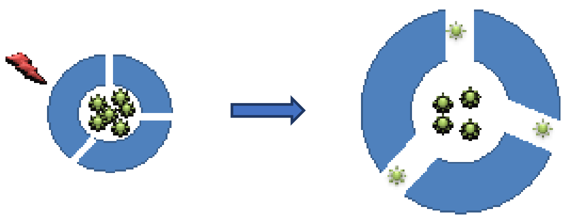

Figure 4: Smart polymeric careers at the right time at right concentration releasing the drug in response to an external stimulus

Remarkable development in this area is an insulin release system which respond to high glucose levels. In one approach, glucose oxidase has been used to generate H^+ for pH –sensitive hydrogels drug career.

Further developments of smart polymer drug delivery have been expanded even to gene therapy. Gene therapy endeavors inserting a good gene into the DNA code. Gene therapy helps to cure genetic diseases, inhibit tumor growth and neurodegenerative diseases. Smart polymers have been investigated as a career to deliver genetic materials into the cell. The career must be cationic to complex with anionic DNA having a net positive charge to interact with negatively charged cell membrane to undergo endocytosis. Attaching the DNA to the career and detaching the DNA from the career required two opposite functions. Interaction between the career and the DNA must be strong at the stage of endosome formation and the detraction must be there between the career and the DNA at the stage of transcription for DNA to move into the nucleus (Figure 5). This duel requirement could easily be achieved by smart polymers where a stimulus can control the binding and detaching the DNA from the career. Thermo-responsive and photo-responsive smart polymers have been investigated on this regard.

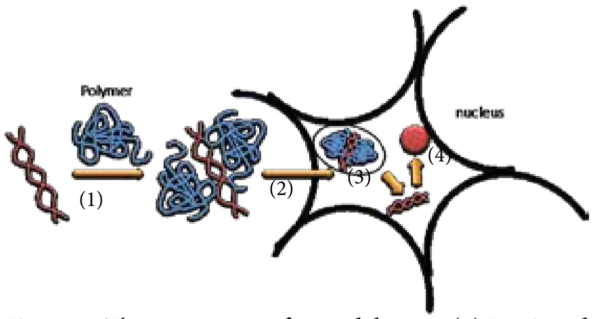

Figure 5: The main steps of gene delivery: (1) DNA and polymer complexation; (2) addition of DNA/polymer complex (sometimes also called polyplex) onto cells for a period of time commonly called the transfection time; (3) removal of complex from the cells; (4) incubation time that is when the cells are left to incubate for a time period until results are observed.

Without a doubt, smart polymers have paved a promising path for applications in the biomedical field. Even though only two such applications, artificial muscles and drug delivery systems, have been discussed here, there are many other applications such as tissue engineering scaffolds, cell culture supports, bio-separation devices, sensors and actuators systems. Developing bio-mimetic mechanisms is challenging where it requires employing many disciplines, tools and capabilities. The dream of artificial intelligence is yet to be achieved and on that note smart polymers are an encouraging approach!