SJIF Impact Factor: 3.458

WORLD JOURNAL OF ADVANCE HEALTHCARE RESEARCH

ISSN: 2457-0400
Volume: 2.
Issue: 6.
Page N. 85-87
Year: 2018

Review Article www.wjahr.com

RECAPITULATING THE BIOMEDICAL APPLICATIONS OF SMART MATERIALS

Rupak Kumar[1*] and Srinivasa R. Vulichi[2]

[1]BITS Pilani, Hyderabad Campus, Hyderabad.
[2]SVU College of Pharmaceutical Sciences, SV University, Tirupati.

Received date: 08 October 2018 **Revised date:** 29 October 2018 **Accepted date:** 19 November 2018

Corresponding author: Rupak Kumar
BITS Pilani, Hyderabad Campus, Hyderabad.

ABSTRACT

The Six-Million-Dollar Man, a popular series of television motion pictures in which the character of Lee Major as test pilot whose airplane crashed, in turn resulting in loss of both the legs, an arm, and an eye. Major's character was rebuilt by a skilled physician using advanced biomedical body parts made up of smart materials at a cost of six million dollars as the bionic man (hence the name). This science fiction gave an insight into designing synthetic biological materials and body parts which can respond to the stimulus. Smart materials can respond to external stimuli through their physical, chemical, electrical, magnetic and optical properties. This extraordinary ability of the structures or structural components of materials perform design function. There are multitudes of examples of smart materials that are used in and around us. One of the promising biomedical applications includes design of point of care (POC) device to screen a large population against many non- communicable or communicable diseases. Others applications of smart materials are described in this review.

KEYWORDS: Smart Materials, External Stimuli, Point of care device.

INTRODUCTION

Smart materials are those materials which can respond to external stimuli just like our five sensors. In general, it is a material which responds to its environment (external stimuli) in a timely manner (Fig.1). Three criteria have been used in characterizing smart materials namely: a definite purpose, mean to achieve that purpose and possess a biological pattern of functionality. Their structures, molecular pattern, physical-chemical properties and behavior towards external stimulus lead to many applications that could be fascinating (Fig.2).

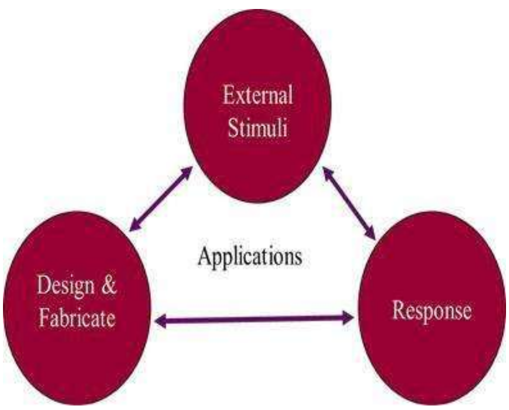

Fig. 1: General view of smart materials.

Fig. 2: Applications of some smart materials.

Expression of Smartness

Various stimuli to which smart materials respond include a change of pH, ionic strength, temperature, or addition of a chemical species. It responds to these external stimuli by making some sense either in their physical, chemical, electrical, magnetic and optical properties which can be read out for quantifying analyte present in a test sample. Smartness of material is expressed in term of measurable intelligence response (IR).

IR = Response/time that causes
= Possible changes
= Measurable quantity*

*color intensity, pH, viscosity, current, temperature, refractive index, magnetism and many more.

Biomedical applications

1. Nitinol shape memory alloy (NT-SMA)

It is a nickel and titanium alloy and popularly known as nitinol or "Night in All". The smartness of nitinol is that it "remembers" its shape (Fig.3).

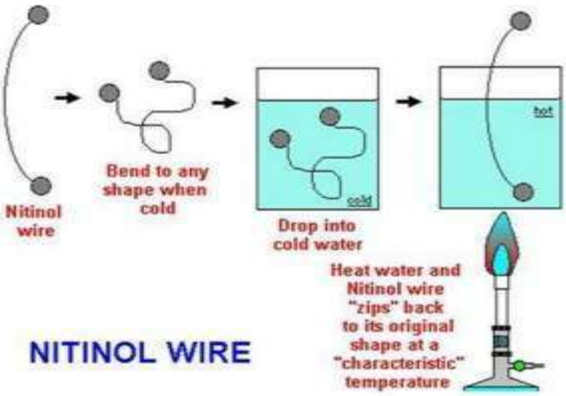

Fig. 3: Smartness of nitinol towards temperature.

One of the important properties of nitinol is that it deforms and regains its shape in accordance to the external temperature stimuli. The Nitinol rod is considerably flexible with less yield strength at low temperatures that is, the material can be deformed quite easily into any desired shape at low temperatures. However, when the material is heated above its activation temperature, it undergoes a change in the crystal structure which causes it to return to its original shape. These distinct characteristics allow it to be used extensively in cardiovascular stents [2,4] and in spine surgery [1,3]. This property serves some important application.

(i). Thermal plastic surgical splint: it is self-molded splint that cast according to body temperature and acquires the desire functional shape (Fig.4).

Fig. 4: Surgical splint.

(ii). To open the blocking of blood vessels at normal body temperature as shown in Fig.5.

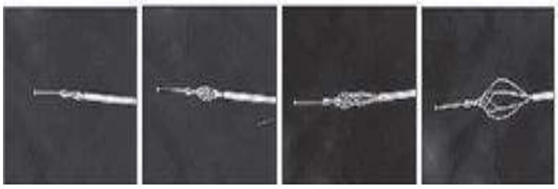

Fig. 5: Opening with artery with nitinol wire.

(iii). Treating severe scoliosis: Yan Wang *et.al*, 2010[5] developed the technique where nitinol rods were used as a temporary tool to straight the spine which later replaced by rigid rod at the end of correction (Fig.6).

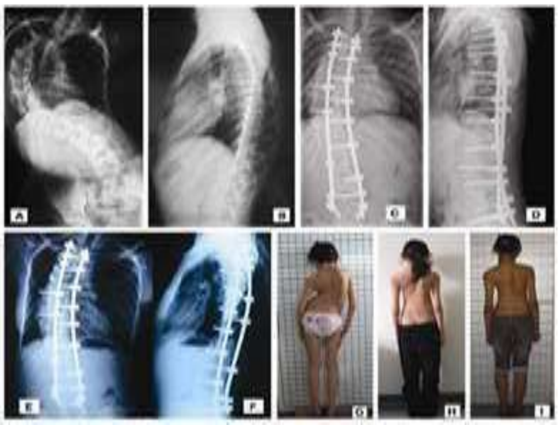

Fig. 6: Recovery for treating severe scoliosis in 14-year-old girl. A and B indicate preoperative anteroposterior and lateral radiograph showed 116º main thoracic scoliosis. C and D show anteroposterior and lateral radiograph taken 3 days after the surgery. The shape memory alloy rods were introduced as temporary tool and the main thoracic curve was corrected to 38º (correction rate 69%). E and F shows anteroposterior and lateral radiographs taken 2 years after the surgery. G, H, and I indicate appearance of preoperative, 1 month postoperative and 2 years postoperative respectively.

(iv). Blood clot filter: The filters are constructed from nitinol wires and are used in one of the outer heart chambers to trap blood clots, which potentially could cause serious health problems if travelling around the blood circulation system. The blood clot filter is available in a compact cylindrical form about 2.0-2.5 mm in diameter. The body heat causes transformation to its functional shape. The wire is shaped to anchor itself in a vein and catch passing clots.[6,7] (Fig. 7).

Fig. 7: The blood–clot filter.

2. Smart chitosan bandage

It is used to coat the wound because chitosan is a positively charged polysaccharide that attracts blood cells which naturally carry a negative electrical charge. This attraction causes an extreme adherence to form a very tight coherent seal over the wound, stabilizing the injured surface and help in speed healing process by reducing the number of inflammatory cells in the wound (Fig. 8). The bandage thus will be useful to enormous people suffering from severely bleeding wounds and others injuries.

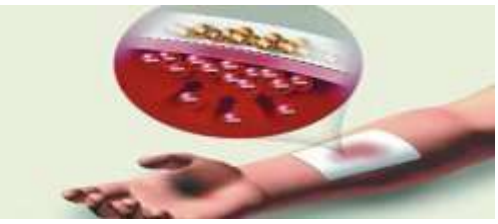

Fig. 8: Application of chitosan bandage in wound healing.

3. Point of care (POC) device

It is a ready to use, portable, light and simple analytical device that could be used by anyone, anywhere, and at any time. It requires less time, quantity and effort to display the result (Fig. 9).

Fig. 9: POC device of different biomedical applications.

Their novel design, material properties and unique analytical capability shows cutting edge research in this field. Different types of smart polymers, chemicals, nanoparticles, and enzymes are used to sense the analyte present in biological fluid. In present days, the market is flooded with such type of devices. It also utilizes dry chemistry (without any reagent preparation) techniques for quantifying a wide range of analytes of clinical importance. The techniques involve impregnation of the reagents including enzymes into immobile support materials or polymers. On adding a drop of test samples such as blood or urine, the analyte in the sample diffuses into the reagents and initiates an enzymatic reaction that results in the production of a colored product. The intensity of color is measured by read out device after a predetermined reaction period. This significant technique is cost- effective, fast, and reliable minimizing access to laboratory facility by scientifically unqualified staff in a country like India, where death due to non-communicable diseases are raising drastically (61% of total death in 2017 due to non-communicable disease in India.[8]).

CONCLUSION

This paper presents a brief review on the basic properties of smart materials and their applications in the biomedical arena. Smart materials have generated significant interest in wide array of biomedical fields because of their functional abilities which enhance the possibility for the development of new surgical tools. The ability of biomolecules to sense and respond appropriately against a specific external stimulus gives a view frame to develop POC devices which could diagnose the disease condition in time prevent its further progression. This method would be applicable under circumstances where there is a lack of both technical and financial resources. Hence, smart materials (especially NT-SMA) are continuously grabbing the attention of many researchers and clinicians of the current biomedical field in addition to its huge demand for commercialization.

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