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Review on Biomedical Instrumentation / Biomedical Engineering and its Various Applications

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ABSTRACT: Bioengineering or Biomedical / Biomedical Instrumentation Engineering involves developing new devices and procedures that solve medical and health-related problems by combining their recent advances knowledge in engineering, biology, and medicine to improve human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. Biomedical engineers may spend their days designing electrical circuits and computer software for medical instrumentation. These instruments may range from large imaging systems such as conventional x-ray, computerized tomography and magnetic resonance imaging, to small implantable devices, such as pacemakers, cochlear implants, drug infusion pumps and some of the prominent biomedical applications include the development of various diagnostic and therapeutic medical devices ranging from common imaging equipment such as MRIs and EEGs, regenerative tissue growth, pharmaceutical drugs and therapeutic biologicals. An evolutionary product is a new model of an existing product that adds new features, improves the technology, and reduces the cost of production. Recent progress of the Nano fibrous structure of chitosan and their biomedical applications in tissue engineering; drug delivery, wound dressing, and antimicrobial are also discussed in this review.

Keywords: Biomedical Engineering, Instrumentation, Imaging, Electrical Circuits and Medical Devices.

I. INTRODUCTION

Bioengineering or Biomedical / Biomedical Instrumentation Engineering involves developing new devices and procedures that solve medical and health-related problems by combining their recent advances knowledge in engineering, biology, and medicine to improve human health through cross-disciplinary activities that integrate the engineering principles and design concepts to medicine and biology for healthcare purposes (e.g. diagnostic or



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therapeutic). This field seeks to close the gap between engineering and medicine: biological sciences to advance healthcare treatment, including diagnosis, monitoring, and therapy.

Bioengineering field is of service to people, work with living systems, and apply advanced technology to the complex problems of medical care. Biomedical engineers may be called upon to design instruments and devices, to bring together knowledge from many sources to develop new procedures, or to carry out research to acquire knowledge needed to solve new problems. It includes:

1. The acquisition of new knowledge and understanding of living systems through the innovative and substantive application of experimental and analytical techniques based on the engineering sciences.
2. The development of new devices, algorithms, processes and systems that advance biology and medicine and improve medical practice and health care delivery.

The term "biomedical engineering research" is thus defined in a broad sense: It includes not only the relevant applications of engineering to medicine but also to the basic life sciences.

Biomedical engineering has only recently emerged as its own study, compared to many other engineering fields. Such an evolution is common as a new field transitions from being an interdisciplinary specialization among already-established fields, to being considered a field in itself. Major advances in Bioengineering include the development of artificial joints, magnetic resonance imaging (MRI), the heart pacemaker, arthroscopy, angioplasty, bioengineered skin, kidney dialysis, and the heart-lung machine. Prominent biomedical engineering applications include the development of biocompatible prostheses, various diagnostic and therapeutic medical devices ranging from clinical equipment to micro-implants, common imaging equipment such as MRIs and EEGs, regenerative tissue growth, pharmaceutical drugs and therapeutic biologicals.

Some biomedical engineers build artificial organs, limbs, knees, hips, heart valves and dental implants to replace lost function; others are growing living tissues to replace failing organs. The development of artificial body parts requires that biomedical engineers use chemistry and physics to develop durable materials that are compatible with a biological environment. Biomedical engineers are also working to develop wireless technology that will allow patients and doctors to communicate over long distances. Many biomedical engineers are involved in rehabilitation—designing better walkers, exercise equipment, robots and therapeutic devices to improve human performance. They are also solving problems at the cellular and molecular level, developing nanotechnology and micro machines to repair damage inside the cell and alter gene function.

Chitin and chitosan have shown to have remarkable biological properties such as bioresorbable degradation products, hydrophilicity, biocompatibility, cellular binding capability, and acceleration of wound healing which accounts for their wide variety of applications in food, cosmetic, biomedical, and pharmaceutical industries Lee *et al.*, (2009). Chitosan has many versatile properties which make it an excellent excipient in controlled release formulations including non-viral vectors for DNA-gene and drug delivery, and imaging applications Agarwal *et al.*, (2010); Sona (2010); Senel (2010) and Remunan (2010). Recently, a library of various polymer-solvent combinations which has a crucial role in transforming chitosan into nanofibers has been developed for many ground breaking applications in different disciplines of biomedical technology such as such as in tissue engineering, wound healing, drug delivery, and anti-bacterial applications Bhattarai *et al.*, (2006); Bhattarai *et al.*, (2005); Tchemtchoua *et al.*, (2011); Jeon *et al.*, (2011); Feng *et al.*, (2010); Chen *et al.*, (2010); Cooper *et al.*, (2011); Bhattarai and Zhang (2007); Shi *et al.*, (2011) and Jung *et al.*, (2007). These studies as well as steady state growth of number of

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publications of chitosan based nanofibers in each year (Figure 1) demonstrate enormous potential of chitosan nanofibers in the biomedical field.

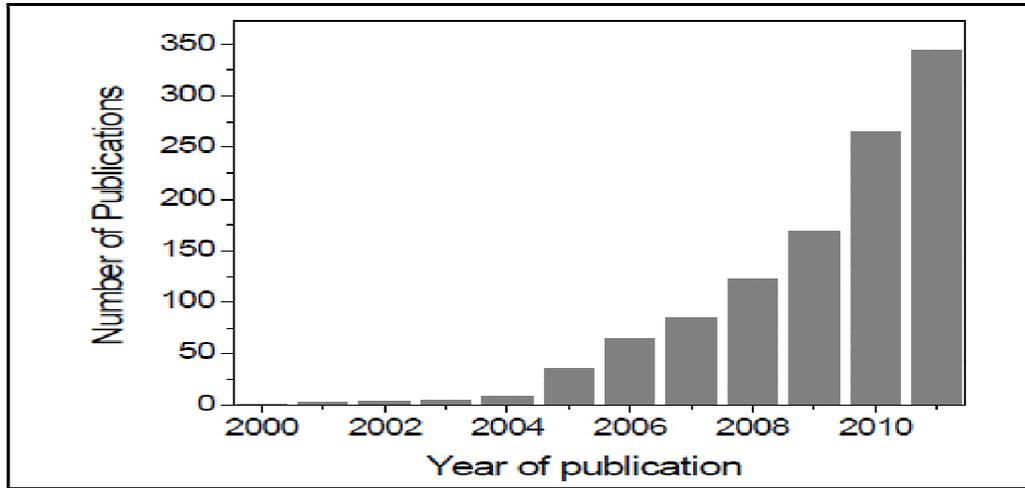


Fig. 1 Steady state growth of number of publications of chitosan based nanofibers in each year.

II. BASIC SENSORS AND PRINCIPLES

Every instrumentation system has at least some of the functional components shown in Figure 2. The primary flow of information is from left to right. Elements and relationships depicted by dashed lines are not essential. The major difference between this system of medical instrumentation and conventional instrumentation systems is that the source of the signals is living tissue or energy applied to living tissue.

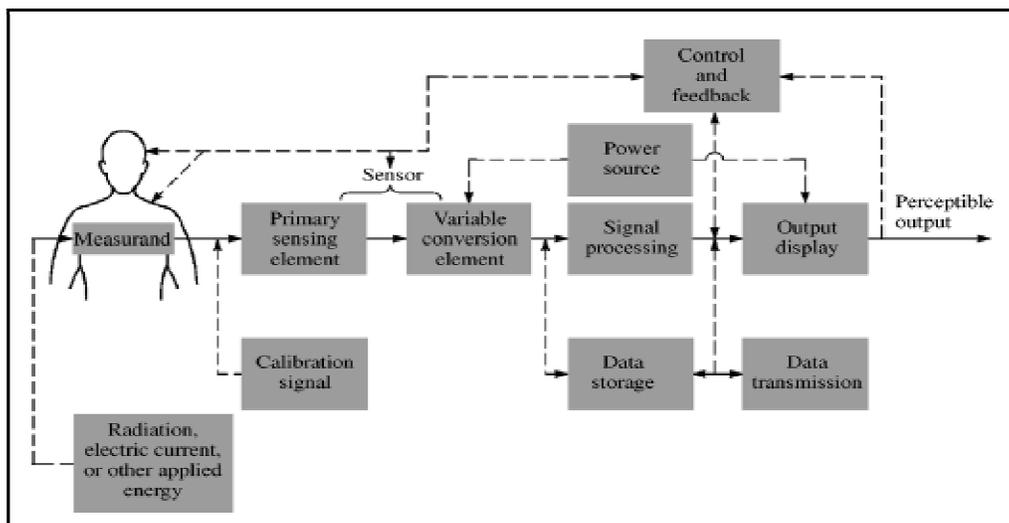


Fig 2. Generalized Instrumentation System.



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The sensor converts energy or information from the measurand to another form (usually electric). This signal is then processed and displayed so that humans can perceive the information. Elements and connections shown by dashed lines are optional for some applications.

[1] MEASURAND

The physical quantity, property, or condition that the system measures is called the measurand. The accessibility of the measurand is important because it may be internal (blood pressure), it may be on the body surface (electrocardiogram potential), it may emanate from the body (infrared radiation), or it may be derived from a tissue sample (such as blood or a biopsy) that is removed from the body. Most medically important measurands can be grouped in the following categories: biopotential, pressure, flow, dimensions (imaging), displacement (velocity, acceleration, and force), impedance, temperature, and chemical concentrations. The measurand may be localized to a specific organ or anatomical structure.

[2] SENSOR

A sensor converts a physical measurand to an electric output. The sensor should respond only to the form of energy present in the measurand, to the exclusion of all others. Many sensors have a primary sensing element such as a diaphragm, which converts pressure to displacement. A variable-conversion element, such as a strain gage, then converts displacement to an electric voltage. Sometimes the sensitivity of the sensor can be adjusted over a wide range by altering the primary sensing element. Many variable-conversion elements need external electric power to obtain a sensor output.

[3] SIGNAL CONDITIONING

Simple signal conditioners may only amplify and filter the signal or merely match the impedance of the sensor to the display. Often sensor outputs are converted to digital form and then processed by specialized digital circuits or a microcomputer (Tompkins and Webster, 1981).

[4] OUTPUT DISPLAY

The results of the measurement process must be displayed in a form that the human operator can perceive. The best form for the display may be numerical or graphical, discrete or continuous, permanent or temporary—depending on the particular measurand and how the operator will use the information. Although most displays rely on our visual sense, some information (Doppler ultrasonic signals, for example) is best perceived by other senses. User controls and the output display should conform to the Human Factors Engineering Guidelines and Preferred Practices for the Design of Medical Devices (AAMI, 1993).

[5] AUXILIARY ELEMENTS

A calibration signal with the properties of the measurand should be applied to the sensor input or as early in the signal-processing chain as possible. Many forms of control and feedback may be required to elicit the measurand, to adjust the sensor and signal conditioner, and to direct the flow of output for display, storage, or transmission. Control and feedback may be automatic or manual. Data may be stored briefly to meet the requirements of signal conditioning or to enable the operator to examine data that precede alarm conditions. Alternatively, data may be stored before signal conditioning, so that different processing schemes can be utilized. Conventional principles of communications can often be used to transmit data to remote displays at nurses' stations, medical centers, or medical data-processing facilities.



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III. CLASSIFICATION OF BIOMEDICAL / BIOMEDICAL INSTRUMENTATION ENGINEERING

Biomedical engineering can be viewed from two angles, from the medical applications side and from the engineering side. A biomedical engineer must have some view of both sides. As with many medical specialties (e.g. cardiology, neurology), some BME sub-disciplines are identified by their associations with *particular systems of the human body*, such as:

- Cardiovascular technology - which includes all drugs, biologics, and devices related with diagnostics and therapeutics of cardiovascular systems.
- Neural technology - which includes all drugs, biologics, and devices related with diagnostics and therapeutics of the brain and nervous systems
- Orthopaedic technology - which includes all drugs, biologics, and devices related with diagnostics and therapeutics of skeletal systems.
- Cancer technology - which includes all drugs, biologics, and devices related with diagnostics and therapeutics of cancer

BME are classified by their association(s) with other more *established engineering fields*, which can include (at a broad level):

a) TISSUE ENGINEERING

Tissue engineering, like genetic engineering is a major segment of Biotechnology - which overlaps significantly with BME. Biomedical engineers are currently researching methods of creating such organs. Researchers have grown solid jawbones and tracheas from human stem cells towards this end. Several artificial urinary bladders actually have been grown in laboratories and transplanted successfully into human patients. Bio artificial organs, which use both synthetic and biological components, are also a focus area in research, such as with hepatic assist devices that use liver cells within an artificial bioreactor construct.

b) GENETIC ENGINEERING

Genetic engineering, recombinant DNA technology, genetic modification/manipulation (GM) and gene splicing are terms that apply to the direct manipulation of an organism's genes. Genetic engineering is different from traditional breeding, where the organism's genes are manipulated indirectly. Genetic engineering uses the techniques of molecular cloning and transformation to alter the structure and characteristics of genes directly. Genetic engineering techniques have found success in numerous applications.

c) NEURAL ENGINEERING

Neural engineering (also known as Neuroengineering) is a discipline that uses engineering techniques to understand, repair, replace, or enhance neural systems. Neural engineers are uniquely qualified to solve design problems at the interface of living neural tissue and non-living constructs.

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d) PHARMACEUTICAL ENGINEERING

Pharmaceutical engineering is an interdisciplinary science that includes drug engineering, novel drug delivery and targeting, pharmaceutical technology, unit operations of Chemical Engineering, and Pharmaceutical Analysis. It may be deemed as a part of Pharmacy due to its focus on the use of technology on chemical agents in providing better medicinal treatment.

e) MEDICAL DEVICES

This is an *extremely broad category*—essentially covering all health care products that do not achieve their intended results through predominantly chemical (e.g., pharmaceuticals) or biological (e.g., vaccines) means, and do not involve metabolism.

A medical device is intended for use in:

- the diagnosis of disease or other conditions, or
- in the cure, mitigation, treatment, or prevention of disease

Some examples include pacemakers, infusion pumps, the heart-lung machine, dialysis machines, artificial organs, implants, artificial limbs, corrective lenses, dental implants etc.,

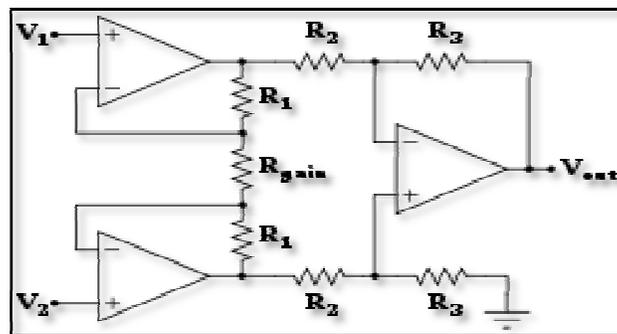


Fig 3. LOW VOLTAGE BIOLOGICAL SIGNALS.

Biomedical instrumentation amplifier schematic used in monitoring low voltage biological signals, an example of a **biomedical engineering** application of electronic engineering to electrophysiology.

Stereo lithography is a practical example of *medical modeling* being used to create physical objects. Beyond modeling organs and the emerging engineering techniques are also currently used in the research and development of new devices for innovative therapies, treatments, patient monitoring, and early diagnosis of complex diseases.

f) MEDICAL IMAGING

In the early 1970s it was believed there was a crisis in health care in the United States, with costs out of control and performance unsatisfactory in many areas. Biomedical engineering was seen as both part of the problem - for raising the costs of health care - and part of the solution - by improving health care.



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Medical/biomedical imaging is a major segment of medical devices. This area deals with enabling clinicians to directly or indirectly "view" things not visible in plain sight (such as due to their size, and/or location). This can involve utilizing ultrasound, magnetism, UV, other radiology, and other means. An MRI scan of a human head, an example of a biomedical engineering application of electrical engineering to diagnostic imaging.

g) IMPLANTS

An implant is a kind of medical device made to replace and act as a missing biological structure (as compared with a transplant, which indicates transplanted biomedical tissue). The surface of implants that contact the body might be made of a biomedical material such as titanium, silicone etc. In some cases implants contain electronics e.g. artificial pacemaker and cochlear implants.

h) BIONICS

Artificial body part replacement is just one of the things that bionics can do. Concerned with the intricate and thorough study of the properties and function of human body systems, bionics may be applied to solve some engineering problems. Biomedical Engineering is the building of useful replacements for various parts of the human body. Modern hospitals now have available spare parts to replace a part of the body that is badly damaged by injury or disease. Biomedical engineers who work hand in hand with doctors build these artificial body parts.

i) CLINICAL ENGINEERING

Clinical engineering is the branch of biomedical engineering dealing with the actual implementation of medical equipment and technologies in hospitals or other clinical settings. Major roles of clinical engineers include training and supervising biomedical equipment technicians (BMETs), selecting technological products/services and logistically managing their implementation, working with governmental regulators on inspections/audits, and serving as technological consultants for other hospital staff (e.g. physicians, administrators, I.T., etc.). Clinical engineers also advise and collaborate with medical device producers regarding prospective design improvements based on clinical experiences, as well as monitor the progression of the state of the art so as to redirect procurement patterns accordingly.

j) STEM CELLS

Stem cells are progenitor cells that have the ability to become any type of cell. Fetal stem cells are the most numerous; but they can be isolated from the adult with difficulty. Stem cells have the ability to repair and even replace injured tissue. The multiple ways of using stem cells is under investigation and future biomedical engineers will certainly be involved with all phases of stem-cell research and therapy.

a) BIONANOTECHNOLOGY

Nanotechnology builds devices one atom at a time, seemingly without limit to the type of device. Biosensors on chips are a reality. The term biochip is becoming popular and can be defined as a micro scale biosensor. It is possible to create sensors for specific proteins by attracting them to their antibodies on chip and detecting their presence by electrical impedance or by fluorescence. The term "laboratory-on-a-chip" is now becoming popular for these nanosensors, which are examples of the diagnostic instrument.

Arrays of nanotechnology microelectrodes have been used to stimulate cortical nerve cells. They have also been implanted to stimulate peripheral nerves. The engineering problems associated with bionanotechnology electrodes are sufficient to challenge any biomedical engineer. Such electrodes must produce a minimal inflammatory



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response, must not be allergenic, must establish a stable electrical interface with the tissue and if used for stimulation, and must not decompose and liberate toxic ions when used for chronic stimulation.

IV. CLASSIFICATIONS OF BIOMEDICAL INSTRUMENTS

The study of biomedical instruments can be approached from at least four viewpoints.

- ✓ Techniques of biomedical measurement can be grouped according to the quantity that is sensed, such as pressure, flow, or temperature. One advantage of this classification is that it makes different methods for measuring any quantity easy to compare.
- ✓ A second classification scheme uses the principle of transduction, such as resistive, inductive, capacitive, ultrasonic, or electrochemical. Different applications of each principle can be used to strengthen understanding of each concept; also, new applications may be readily apparent.
- ✓ Measurement techniques can be studied separately for each organ system, such as the cardiovascular, pulmonary, nervous, and endocrine systems. This approach isolates all important measurements for specialists who need to know only about a specific area, but it results in considerable overlap of quantities sensed and principles of transduction.
- ✓ Finally, biomedical instruments can be classified according to the clinical medicine specialties, such as pediatrics, obstetrics, cardiology, or radiology. This approach is valuable for medical personnel who are interested in specialized instruments. Of course, certain measurements - such as blood pressure - are important to many different medical specialties.

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V. BASIC CONCEPTS OF BIOMEDICAL INSTRUMENTATION

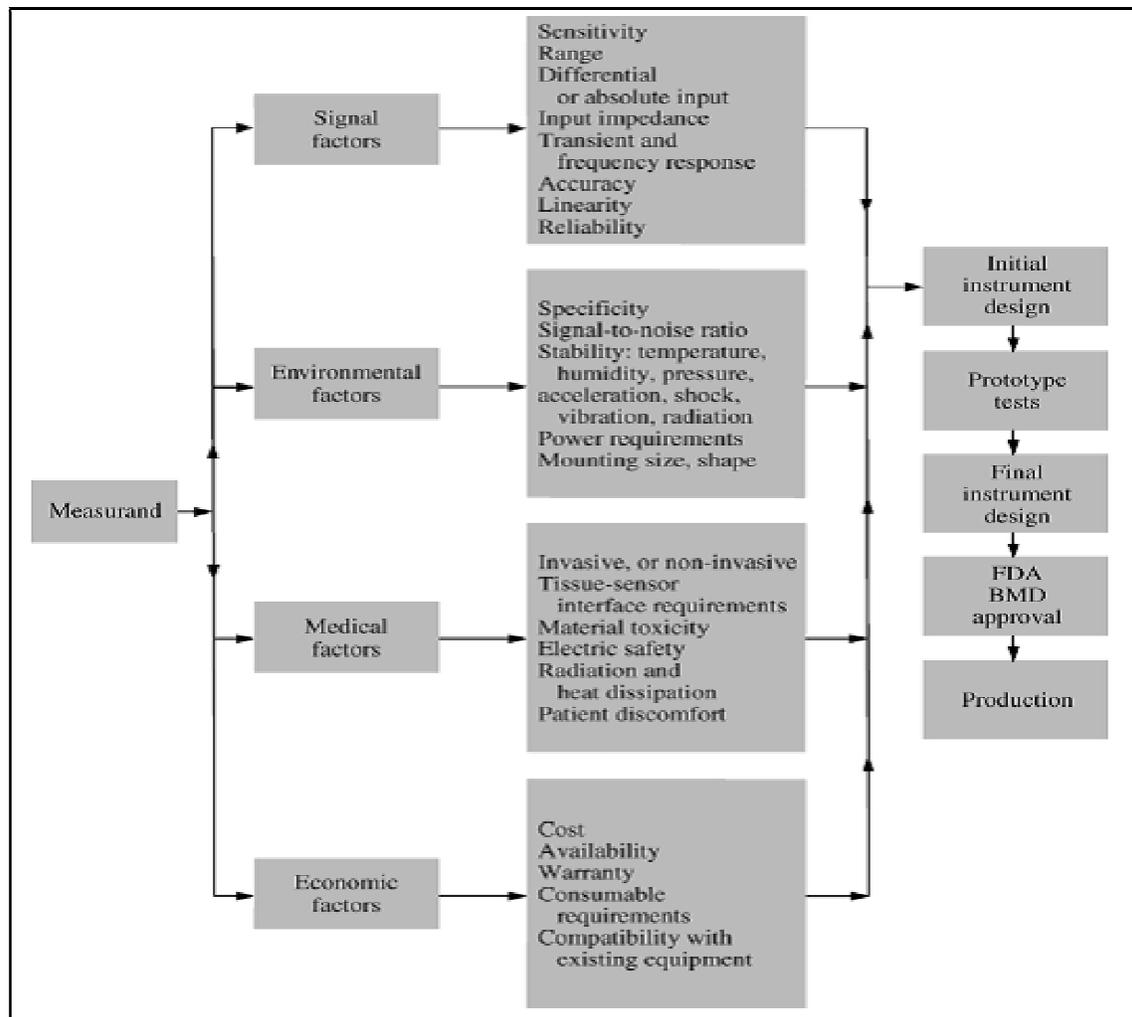


Fig 4. DESIGN PROCESS FOR MEDICAL INSTRUMENTS

Choice and design of instruments are affected by signal factors and also by environmental, medical, and economic factors. (Revised from Transducers for Biomedical Measurements: Application and Design, R. S. C. Cobbold. Copyright 1974, John Wiley and Sons, Inc. Used by permission of John Wiley and Sons, Inc.)

VI. APPLICATIONS IN BIOMEDICAL / BIOMEDICAL INSTRUMENTATION ENGINEERING

1. BIOMEDICAL APPLICATIONS IN EMBEDDED SYSTEMS



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The integration of *embedded healthcare devices and systems* into a global context involves local and large scale infrastructures with many dependencies affecting the dependable function of the system

- Positive influence on the broad area of telemedicine is envisaged.
- Healthcare applications offer distinctive challenges for embedded systems over the next ten years for the following reasons.

Ambient intelligence is the ability to assist in a wide range of tasks by mapping more of the human actors work process into the environment.

- Deeper interpretation of sensed data and allows control of local actuators to take account of more global context for the activity.
- Embedded systems are essential for the implementation of the reliable infrastructure to support *AmI and wireless sensors and actuators*.

Healthcare applications-massive demands on data capacity, extensive use of imaging and other data intensive monitoring technologies

- Large knowledge bases at the point of delivery of care.
- Ambient, pervasive embedded systems with the high performance, data intensive facilities provided by e-science facilities.
- Specific embedded architectures with the emerging grid service architectures.
- Health systems also involve complex ethical, privacy and security issues because they involve sensitive personal data.
- Hybrid electronic/biological systems that are both informatics and biologically active -augmentation with genetic data.

VII. BIOMEDICAL IN BIOTECHNOLOGICAL APPLICATIONS

- ✓ For biotechnological and biomedical applications, such as medical devices and textiles for wound dressings, it is desirable that the coatings should not only show an antifouling effect but also show an antibacterial effect.
- ✓ The PEO - like coatings discussed in the previous section show good antifouling (protein and cell repellent) properties, but have no antibacterial properties. It is, therefore, desirable to further engineer the PEO (Poly ethylene Oxide) - like films toward those properties.

VIII. BIOMEDICAL AND NUTRACEUTICAL APPLICATIONS OF COLLAGEN AND GELATIN

- Collagen is commonly used in medical and pharmaceutical industries as carrier molecules for drugs, proteins and genes Lee *et al.*, (2001). Especially, microfibrillar collagen sheets are used as promising drug carrier for the treatment of cancer Sato *et al.*, (1996). Long term maintenance of drug concentration and controlled release at target sites promote the utilization of collagen as efficient drug carriers.
- In addition, recently collagen film/matrix is used as gene delivery agents promoting bone and cartilage formation Nakagawa & Tagawa (2000). Further, collagen has been reported to play a role in formation of tissues and organs and functional expression of cells.



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- Clinical investigations suggest that ingestion of collagen/gelatin hydrolysates reduces pain in patients suffering from osteoarthritis and hydrolyzed collagen have been involved in cartilage matrix synthesis Moskowitz *et al.*, (2000). Moreover, collagen/gelatin is currently marketed as supplement for the maintenance of normal bone integrity, treatment for brittle nails and for the nourishment of scalp hair.

IX. BIOMEDICAL APPLICATIONS OF NANOFIBERS

- One of the most important fields of nanofiber use is biomedical applications. Biomedicine accounts for two thirds of nanofiber applications, filtration covers a sixth, and the remainder is divided among other applications (protective clothing, optical electronics, etc.). The main applications of nanofibers in biomedicine involve tissue engineering, drug delivery, and wound healing bandages.
- Tissues are composite materials made up of cells and a matrix material known as the extracellular matrix (ECM). The matrix helps to provide support and guidance for cells as they grow and develop functions. Because of the size, high surface area and porosity of electrospun nanofibers they have the potential to be an excellent replacement for a natural ECM, which opens the door for many medical related applications Ma *et al.*, (2005); Dviret *et al.*, (2005); Venugopal and Ramakrishna (2005) and Duan *et al.*, (2004).
- Nanofibers are an interesting material for biomedical applications for many reasons. Compared with most materials, the surface area of nanofibers, allowing for the adhesion of cells, proteins and drugs, is much larger. In fact, many *in vitro* studies of nanofiber wound healing bandages, tissue engineering scaffolds and drug carriers have shown that nanofiber materials outperform their micro or macro counterparts even when they are composed of the same materials. The properties of nanofiber layers, such as porosity, can generally be adapted.

X. BIOMEDICAL AND ITS APPLICATIONS IN FOOD INDUSTRY

- ✓ Pectin has long standing reputation of being non- toxic Watts and Smith (2009), their relatively low production cost Sungthongjeen *et al.*, (2004) and high availability Beneke *et al.*, (2009). It was proposed that pectin can be used for delivering drugs orally, nasally, and vaginally Peppaset *et al.*, (2000); Sinha and Kumria (2001); Nafee *et al.*, (2004); Valenta 2005; Chelladurai *et al.*, (2008) and Thirawong *et al.*, (2008) and it has been well accepted by patients Yadav *et al.*, (2009).
- ✓ Several pectin formulations (hydrogels, films, microspheres and nanoparticles) has been used so far targeting various proteins and drugs. There is already few excellent review articles published on pectin and its controlled delivery applications Liu *et al.*, (2007); Willatset *et al.*, (2006); Voragen *et al.*, (2009); Lui *et al.*, (2003) and Sriamornsak 2011. In this article we will review the recent research on various pectin based formulations being investigated for various biomedical applications.
- ✓ Natural polymers have clear advantage over synthetic counterparts because of their biodegradable and biocompatible nature. However the mechanical strength of natural polymer formulation is less as compared to synthetic polymers which makes them vulnerable for various biomedical applications.
- ✓ Polysaccharides have recently been investigated for preparation of nanoparticles because of their excellent physicochemical properties and biocompatible nature which is beneficial for biomedical use Dou *et al.*, (2003); Hu *et al.*, (2003) and Tang *et al.*, (2006).



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XI. CONCLUSION

Bioengineering/Biomedical Engineering/ Biomedical Instrumentation Engineering combines engineering expertise with medical needs for the enhancement of health care. Biomedical engineers may be called upon to design instruments and devices, to bring together knowledge from many sources to develop new procedures, or to carry out research to acquire knowledge needed to solve new problems. Biomedical engineering (BME) is an interdisciplinary field whose scope is exceptionally wide and ranges from nanomedicine to space medicine, from molecular and cellularengineering to robotics applied in surgery, and from neuromuscular systems to many devices such as mechanical heart pumps and the artificial lung.

Bioinstrumentation is the application of electronics and measurement principles and techniques to develop devices used in diagnosis and treatment of disease. Computers are becoming increasingly important in bioinstrumentation, from the microprocessor used to do a variety of small tasks in a single purpose instrument to the extensive computing power needed to process the large amount of information in a medical imaging system.

Nanofibers prepared from electro spinning of chitosan represent a simple, efficient and scalable method that is well suited to prepare clinically relevant materials. Whether it's the regeneration of nerve tissue, delivery of anti-inflammatory drugs, or keeping a wound sterilized from infection, each form of biomedical application requires extensive research. Pectin is one of extensively studied natural biodegradable polymer formulations for drug delivery, wound dressing and tissue engineering. So far, a limited number of bioactivities have been identified from isolated compounds and further researches are needed to develop methods to apply them for the human health promotion.

Biomedical engineering leaders are currently challenged by the task of better defining the infrastructure of biomedical engineering, its multidisciplinary nature, and the processes employed to educate new engineers in this changing field. Biomedical engineers of the future will have to be more aware of applicable governmental regulations, which set standards for efficacy and safety. If we substitute “biomedical engineer” for “mechanic” and “technology” for “handicrafts” and “mechanical science,” we have established the credentials for biomedical engineers of the future, no matter what he or she may do.

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