Biomedical engineering

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An interdisciplinary field in which the principles, laws, and techniques of engineering, physics, chemistry, and other physical sciences are applied to facilitate progress in medicine, biology, and other life sciences. Biomedical engineering encompasses both engineering science and applied engineering in order to define and solve problems in medical research and clinical medicine for the improvement of health care. Biomedical engineers must have training in anatomy, physiology, and medicine, as well as in engineering.

Biomedical engineering entails the design and development of tools and instrumentation to enhance the ability of physicians and life scientists to obtain information on physiological and biological processes, and to aid in the treatment of diseases or other abnormalities. It is also an important component in the design and development of artificial organs, limbs, and other prosthetic devices that replace missing body parts or that enhance deteriorated physiological functions. Biomedical engineering also contributes to medical and biological research aimed at learning more about the functional processes in various physiological systems. An important part of biomedical engineering research is the use of computer techniques to develop mathematical models of physiological functions and processes to expand available theoretical knowledge. *See also:* **Simulation (/content/simulation/624700)**

The impact of biomedical engineering is manifested in the many instruments and devices that surround a patient in the modern hospital and in the many sophisticated artificial organs and other prosthetic devices available. In addition, biomedical engineering contributes greatly to medical and biological research.

Instrumentation

A wide variety of instrumentation is available to the physician and surgeon to facilitate the diagnosis and treatment of diseases and other malfunctions of the body. Instrumentation has been developed to extend and improve the quality of life. A primary objective in the development of medical instrumentation is to obtain the required results with minimal invasion of the body. Invasion refers to the penetration of the skin or external integument, usually involving increased risk and trauma to the patient. A device in the stomach accessed through the throat is not invasive, in contrast to a needle penetrating the skin to withdraw blood from a vein, or a blood pressure transducer at the tip of a catheter introduced into a blood vessel. In a broader sense, exposing the body to x-radiation or radioisotopes can also be considered invasive.

Diagnostic instrumentation

Medical diagnosis requires knowledge of the condition of specified organs or systems of the body, and a vast array of instrumentation has been developed. Bioelectric potentials, that is, electrical signals generated within the body, provide a useful source of information. Much can be learned about the functioning of the heart by using electrocardiography (EKG) to measure and analyze the electrical activity of the heart. Electrocardiographic signals are used to measure heart rate and to identify certain types of abnormalities within the heart. They also serve as a means of synchronizing other measurements with cardiovascular activity. Neurological activity within the brain can be assessed by using electroencephalography (EEG) to measure and analyze the electrical activity of the brain. Muscular activity can be measured by using electromyography (EMG), which utilizes the electrical activity of muscles. These bioelectric potentials are generally obtained noninvasively, but localized measurements may require placement of electrodes at sites that require invasive procedures. Neurological measurements usually require invasive placement of electrodes within or adjacent to specific nerves or neurons. Although bioelectric potentials have been used clinically for several decades, improved electrode design and instrumentation have made these measurements more reliable and have increased their usefulness. *See also:* **Biopotentials and ionic currents (/content/biopotentials-and-ionic-currents/083900)**; **Cardiac electrophysiology (/content/cardiac-electrophysiology /109600)**; **Electrodiagnosis (/content/electrodiagnosis/221000)**; **Electroencephalography (/content /electroencephalography/221300)**

Sounds generated within the body constitute another source of information. Notable are heart sounds corresponding to the pumping action of the heart and operation of the heart valves; and sounds generated by blood pulsating through a partially occluded vessel, used in indirect blood pressure measurements.

Electrical impedance measurements are utilized to obtain information noninvasively. Impedance plethysmography is a technique by which changes in the volume of certain segments of the body can be determined by impedance measurements. These changes are related to factors involving the mechanical activity of the heart such as cardiac output, or conditions of the circulatory system such as blood volume and flow in various regions, or to respiratory flow and other physiological functions.

Ultrasound is utilized in many types of diagnostic measurements. In most applications, periodic bursts of ultrasound are introduced into a region of the body, and echoes from various structures and organs are measured. Echocardiography is an ultrasound procedure which provides an indication of the physical movements of the walls and valves of the heart. Echoencephalography involves ultrasonic echoes from the midline of the brain to detect tumors that would shift that midline. Electronically produced images of various internal organs and body structures are obtained by using different types of ultrasonic scans. All of these measurements are performed noninvasively. *See also:* **Echocardiography (/content /echocardiography/211600)**; **Medical ultrasonic tomography (/content/medical-ultrasonic-tomography/413050)**

X-rays have long been utilized to visualize internal body structures, but computerized tomographic methods and other improvements have greatly increased their diagnostic potential, permitting measurements with reduced radiation exposure to the patient. Also, better contrast media have been developed to make organs or regions of interest more clearly identifiable in the x-ray image. *See also:* **Computerized tomography (/content/computerized-tomography/154300)**; **Radiography (/content/radiography/569700)**; **Radiology (/content/radiology/570700)**

Another imaging process is magnetic resonance, which requires excitation of the site of measurement by an alternating magnetic field in the radio-frequency range. Magnetic resonance utilizes the principle that the nuclei of certain elements resonate when excited by a given radio frequency. Different elements have different resonance characteristics for identification. Like ultrasound, the excitation required for magnetic resonance measurements has not shown any indication of harming the body. *See also:* **Medical imaging (/content/medical-imaging/412850)**; **Nuclear magnetic resonance (NMR) (/content/nuclear-magnetic-resonance-nmr/459000)**

Imaging of organs and body structures has been greatly enhanced by computerized tomography. A number of linear scans through a given cross section of the organ or body are taken from different vantage points and combined mathematically by computer to produce a cross-sectional image in which all features are clearly shown. Tomography applied to x-ray images produces computerized tomography or computerized axial tomography (CAT) scans. When radioisotopes are used, the result is called positron emission tomography (PET) or single photon emission computerized tomography (SPECT). Computerized tomography is also applied to obtain images from other types of measurements. For example, tomographic imaging from electrical impedance measurements within the body is called electrical impedance tomography (EIT).

Monitoring equipment found at the bedside of each patient in the intensive care unit of a hospital combines a number of biomedical measurement devices to perform continuous noninvasive measurements of body temperature, heart rate, blood pressure, respiration, blood gases, and other variables that indicate the condition of the patient and that alert hospital personnel to an impending emergency. Noninvasive transcutaneous sensors permit reliable measurement of blood gases, oxygenation, and other factors in the blood. Telemetry makes it possible to monitor many of these physiological variables from an ambulatory person.

There are still many clinical situations in which noninvasive measurements are unable to provide adequate data. For example, systolic and diastolic blood pressure can be measured noninvasively by using an indirect method involving occluding cuffs and detection of the sounds of blood flowing through the occlusions. However, measurement of the actual blood pressure waveform itself is often required, and a blood pressure transducer must be carried by a catheter to a specified location within the cardiovascular system. Similarly, blood flow through a major artery or region of the body can be estimated or traced qualitatively from a probe outside the body, but reliable quantitative measurements still require invasive procedures. These examples from the cardiovascular system are typical of similar problems in nearly all of the physiological systems of the body.

Therapeutic instrumentation

Instrumentation is used in many ways for the treatment of disease. Devices are available to provide control for the automated administration of medication or other substances such as insulin for diabetics. In some cases, the rate at which the substance is administered is controlled by the level of certain constituents of the blood or other body fluids. Examples of this equipment may be found in the hospital, where the medication is administered to a patient who is in bed or whose movement is otherwise restricted. Other devices are designed to be worn on the body or even implanted within the body. *See also:* **Drug delivery systems (/content/drug-delivery-systems/757275)**

Implanted pacemakers have been available for some time, but improvements have made them more sensitive to the natural function of the heart and the demands of the body. Such pacemakers monitor the patient's electrocardiogram and other physiological data and stimulate the heart only when the natural functions become insufficient to meet demands. The size and life of the batteries powering such devices have been improved, thus reducing the need for surgery to replace pacemaker batteries. Implantable defibrillators are available for special situations in which periodic automatic defibrillation is required to maintain functionality of a heart.

Another therapeutic technique involves the application of electrical stimulation to muscles or nerves to block involuntary muscle contractions or pain. The stimulating electrodes can be implanted or can be placed on the surface of the skin, depending on the depth of the site to be stimulated.

Surgical equipment

A number of tools are available to the surgeon in the operating room in addition to the monitoring instruments. The family of electrosurgical tools uses highly concentrated electric currents to precisely cut tissue and at the same time control bleeding.

Lasers, which deliver highly concentrated light energy, are also used for making incisions and for fusion of tissue, as in the reattachment of the retina in the eye. *See also:* **Surgery (/content/surgery/671500)**

Clinical engineering

Responsibility for the correct installation, use, and maintenance of all medical instrumentation in the hospital is usually assigned to individuals with biomedical engineering training. This phase of biomedical engineering is termed clinical engineering, and often involves providing training for physicians, nurses, and other hospital personnel who operate the equipment. Another responsibility of the clinical engineer is to ensure that the instrumentation meets functional specifications at all times and poses no safety hazard to patients. In most hospitals, the clinical engineer supervises one or more biomedical engineering technicians in the repair and maintenance of the instrumentation.

Biomedical research

The application of engineering principles and techniques has a significant impact on medical and biological research aimed at finding cures for a large number of diseases, such as heart disease, cancer, and AIDS, and at providing the medical community with increased knowledge in almost all areas of physiology and biology. The data obtained by medical and biological research are also used to develop more realistic and sophisticated prosthetic devices, making possible better methods of control and better understanding of the natural systems that the prostheses are designed to replace.

Biomedical engineers are involved in the development of instrumentation for nearly every aspect of medical and biological research, either as a part of a team with medical professionals or independently, in such varied fields as electrophysiology, biomechanics, fluid mechanics, microcirculation, and biochemistry. A number of fields, such as cellular engineering and tissue engineering, have evolved from this work.

Physiological modeling

A significant role for biomedical engineers in research is the development of mathematical models of physiological and biological systems. A mathematical model is a set of equations that are derived from physical and chemical laws and that describe a physiological or biological function. Experimental data obtained under conditions for which the model is expected to be valid can be used to test the model, which can then be used in several ways to represent the function or process for which it was created. By utilizing computer implementation, mathematical models can be used to predict the effect of given events, such as the administration of a given drug or treatment.

Modeling can be done at various physiological levels, from the cellular or microbiological level to that of a complete living organism, and can be of various degrees of complexity, depending on which kinds of functions they are intended to represent and how much of the natural function is essential for the purpose of the model. Mechanical, neurological, neuromuscular, electrochemical, biochemical, thermal, biological, metabolic, pneumatic (pulmonary), hydraulic (cardiovascular), and behavioral (psychological) systems are among the many types of systems for which models have been developed and studied. The models involve transport, utilization, and control of mass, energy, momentum, and information within these systems. A major objective of biomedical engineering is to create models that more closely approximate the natural functions they represent and that satisfy as many of the conditions encountered in nature as possible. *See also:* **Mathematical biology (/content/mathematical-biology/409700)**

Artificial organs and prosthetics

A highly important contribution of biomedical engineering is in the design and development of artificial organs and prosthetic devices which replace or enhance the function of missing, inoperative, or inadequate natural organs or body parts.

Hemodialysis units, which perform the functions of the kidney, have been in use for a long time, but most are large external devices that must be connected to the patient periodically to remove wastes from the body. A major goal in this area is to develop small, self-contained, implantable artificial organs that function as well as the natural organs, which they can permanently supersede.

Artificial hips, joints, and many other body structures and devices designed to strengthen or reinforce weakened structures must be implanted and must function for the life of the patient. They must be made of biocompatible materials that will not cause infection or rejection by the body. They must be built with sufficient reliability that the need for adjustment, repair, or replacement will be minimized.

Sophisticated artificial limbs for amputees and neural prostheses to facilitate or strengthen the use of nonfunctional limbs is another area in which biomedical engineers are involved. Prosthetic limbs attempt to replicate the vital features of natural limbs with miniature electric motors acting as muscles to operate the moving parts. Control of the movements is a major challenge, especially for the arm and hand, where there is a particular need to provide dexterity for the user. Electromyographic signals from muscles remaining in the stump and elsewhere in the body are utilized where possible. However, the limitations are severe, and the ability of the user to learn to operate the device effectively poses a further problem. The problem is compounded by the need for sensory feedback from the prosthesis in order to provide smooth control. Simple on-off switching operations can be accomplished by moving a part of the body such as the shoulder, by placing a device in the mouth that can be operated by the tongue, by a puff-sip action, or by other motions within the physical capability of the patient.

Neural prostheses bypass a portion of the nervous system and provide electrical stimulation to existing muscles in situations where paralysis has interrupted the natural control pathways. The electrical stimulation can be applied either along the surface of the skin over the muscles to be stimulated or via electrodes implanted within or immediately adjacent to the muscle. Control of the muscle action when using these prostheses is even more difficult than with artificial limbs, especially if the sensory path from the muscle has also been interrupted. Some success has been achieved in providing functional electrical stimulation to specified muscles in the foot to overcome a condition called drop foot. The stimulation is controlled by a switch activated by the position of the foot at a specified portion of the walking cycle. Neural prostheses for the lower limbs have been successful in helping paralyzed patients walk to a limited degree. *See also:* **Prosthesis (/content/prosthesis/549700)**

Rehabilitation engineering

The goal of rehabilitation engineering is to increase the quality of life for the disabled. One major part of this field is directed toward strengthening existing but weakened motor functions through use of special devices and procedures that control exercising of the muscles involved. Another part is devoted to enabling disabled persons to function better in the world and live more normal lives.

Included in this area are devices to aid the blind and hearing-impaired. Hearing aids are available to assist persons in which the acoustical signal has weakened. Cochlear implants that bypass the hair cells and directly stimulate the auditory nerve make it possible to restore some hearing ability to many individuals. Reading machines that either produce greatly enlarged images or convert written words into sound have been developed to assist the visually impaired. All of these devices have their shortcomings, and work to create improved visual and auditory aids continues. *See also:* **Hearing aid (/content/hearing-aid/309700)**

Human-factors engineering is utilized in modifying the home and workplace to accommodate the special needs of disabled persons. Improved wheelchairs and wheelchair control devices and modified automobile control mechanisms permit greater mobility for many who are unable to walk or drive a conventional vehicle. Special modifications to the control mechanisms of television sets and other devices and appliances in the home allow for use by people with disabilities. *See also:* **Biomechanics (/content/biomechanics/083500)**; **Human-factors engineering (/content/human-factors-engineering/324510)**; **Medical control systems (/content/medical-control-systems/412800)**

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