Sloan Career Cornerstone Center

# Bioengineering Overview

**The Field - Preparation - Accreditation - Day in the Life - Specialty Areas - Earnings - Employment - Career Path Forecast - Major Advances in Bioengineering - Professional Organizations**

## The Field


Research at Georgia Tech/Emory Center for the Engineering of Living Tissues. Credit: GTEC

Bioengineering or Biomedical Engineering is a discipline that advances knowledge in engineering, biology, and medicine -- and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice.

Bioengineering/Biomedical Engineering combines engineering expertise with medical needs for the enhancement of health care. It is a branch of engineering in which knowledge and skills are developed and applied to define and solve problems in biology and medicine.

Those working within the bioengineering field are 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.

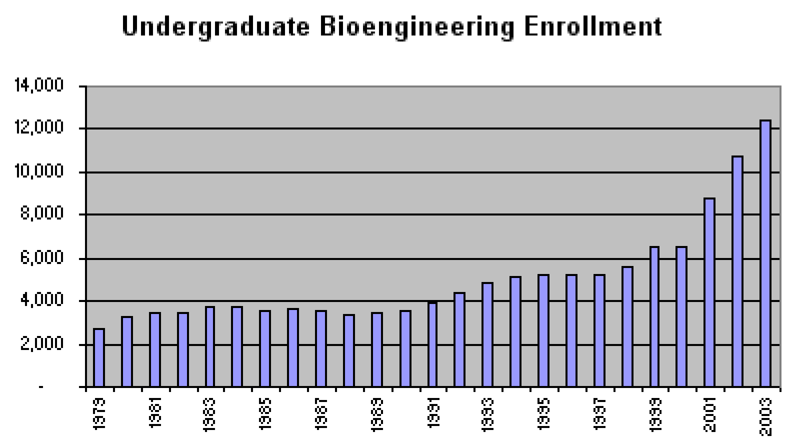
Major advances in Bioengineering include the development of artificial joints, magnetic resonance imaging (MRI), the heart pacemaker, arthroscopy, angioplasty, bioengineered skin, kidney dialysis, and the heart-lung machine.

## Preparation

A bachelor's degree in engineering is required for almost all entry-level engineering jobs. Unlike many other engineering specialties, a graduate degree may be recommended or required for some entry-level jobs in bioengineering. College graduates with a degree in a physical science or mathematics occasionally may qualify for some engineering jobs, especially in specialties in high demand. Most engineering degrees are granted in electrical, electronics, mechanical, chemical, civil, or materials engineering. However, engineers trained in one branch may work in related branches. For example, some biological engineers also have training in mechanical engineering. This flexibility allows employers to meet staffing needs in new technologies and specialties in which engineers may be in short supply. It also allows engineers to shift to fields with better employment prospects or to those that more closely match their interests.

At the college level, the student usually selects engineering as a field of study, then chooses a discipline concentration within engineering. Some students will major in bioengineering or biomedical engineering, while others may major in a traditional field such as electrical, mechanical, or chemical engineering, with a specialty in biomedical engineering.

Most engineering programs involve a concentration of study in an engineering specialty, along with courses in both mathematics and science. Most programs include a design course, sometimes accompanied by a computer or laboratory class or both.




**Source: Engineering Workforce Commission of the American Association of Engineering Societies.**

## Admission Requirements

Admissions requirements for undergraduate engineering schools include a solid background in mathematics (algebra, geometry, trigonometry, and calculus) and science (biology, chemistry, and physics), and courses in English, social studies, humanities, and computer and information technology. Bachelor's degree programs in engineering typically are designed to last 4 years, but many students find that it takes between 4 and 5 years to complete their studies. In a typical 4-year college curriculum, the first 2 years are spent studying mathematics, basic sciences, introductory engineering, humanities, and social sciences. In the last 2 years, most courses are in engineering, usually with a concentration in one branch.

## Co-ops

Internships and Coops provide students with a great opportunity to gain real-world experience while still in school. In addition to giving students direct experience in the field they are considering, interaction with others in the field can help provide perspective on career path options.

## High School Prep

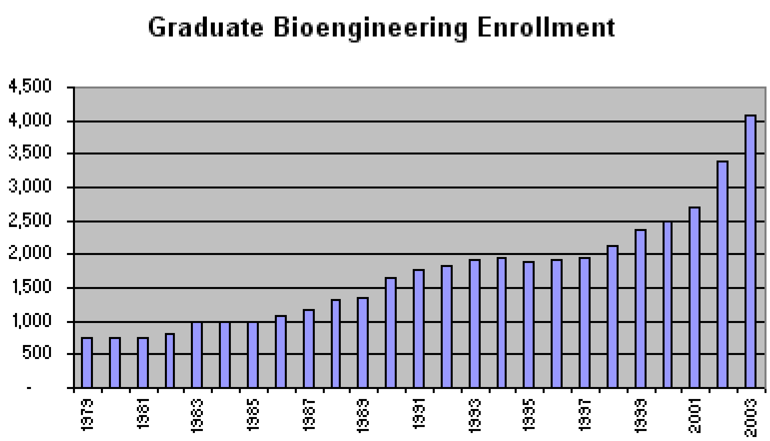
The high school preparation for bioengineering is the same as for any other engineering discipline, except that some life science course work should also be included.

## Alternate Degree Paths

Some engineering schools and 2-year colleges have agreements whereby the 2-year college provides the initial engineering education, and the engineering school automatically admits students for their last 2 years. In addition, a few engineering schools have arrangements whereby a student spends 3 years in a liberal arts college studying pre-engineering subjects and 2 years in an engineering school studying core subjects, and then receives a bachelor's degree from each school. Some colleges and universities offer 5-year master's degree programs. Some 5-year or even 6-year cooperative plans combine classroom study and practical work, permitting students to gain valuable experience and to finance part of their education.

## Graduate Training

Graduate training is essential for engineering faculty positions and many research and development programs, but is not required for the majority of entry-level engineering jobs. Many engineers obtain graduate degrees in engineering or business administration to learn new technology and broaden their education. Many high-level executives in government and industry began their careers as engineers. It is important to select a degree program that has been accredited.




Source: Engineering Workforce Commission of the American Association of Engineering Societies.

# Accreditation

Those interested in a career in Bioengineering should consider reviewing engineering programs that are accredited by the Accreditation Board for Engineering and Technology, Inc. (ABET). ABET accreditation is based on an evaluation of an engineering program's student achievement, program improvement, faculty, curricular content, facilities, and institutional commitment.  The following is a list of universities offering accredited degree programs in Biological Engineering/Biomedical Engineering.

- **Arizona State University**
- **Boston University**
- **Brown University**
- **Case Western Reserve University**
- **Columbia University**
- **Drexel University**
- **Duke University**
- **Florida International University (University Park)**
- **Georgia Institute of Technology**
- **Lehigh University**
- **Louisiana Tech University**
- **Marquette University**
- **Michigan Technological University**
- **Milwaukee School of Engineering**
- **New Jersey Institute of Technology**
- **North Carolina State University at Raleigh**
- **Northwestern University**
- **Oregon State University**
- **Purdue University at West Lafayette**
- **Rensselaer Polytechnic Institute**
- **Rose-Hulman Institute of Technology**
- **Rutgers, The State University of New Jersey**
- **Saint Louis University**
- **State University of New York at Binghamton**
- **Stony Brook University**
- **Syracuse University**
- **Texas A & M University**
- **The Catholic University of America**
- **The George Washington University**
- **The Johns Hopkins University**
- **The University of Akron**
- **The University of Toledo**
- **Tulane University**
- **University of Alabama at Birmingham**
- **University of California, Irvine**
- **University of California, San Diego**
- **University of Central Oklahoma**
- **University of Cincinnati**
- **University of Connecticut**
- **University of Hartford**
- **University of Illinois at Chicago**
- **University of Iowa**
- **University of Miami**
- **University of Michigan**
- **University of Minnesota-Twin Cities**
- **University of Pennsylvania**
- **University of Pittsburgh**
- **University of Rochester**
- **University of Tennessee at Knoxville**
- **University of Texas at Austin**
- **University of Virginia**
- **University of Washington**
- **University of Wisconsin-Madison**
- **Vanderbilt University**
- **Virginia Commonwealth University**
- **Washington State University**
- **Washington University**
- **Western New England College**
- **Worcester Polytechnic Institute**
- **Wright State University**

## Day in the Life

By combining biology and medicine with engineering, biomedical engineers develop devices and procedures that solve medical and health-related problems. Bioengineers will be working closely with medical doctors and medical assistants -- in teams to solve a wide range of challenges.

Close-up of tissue-engineered construct, a combination of living cells and porous biomaterial. Photo Credit: Georgia Institute of Technology

Many do research, along with life scientists, chemists, and medical scientists, to develop and evaluate systems and products for use in the fields of biology and health, such as artificial organs, prostheses (artificial devices that replace missing body parts), instrumentation, medical information systems, and health management and care delivery systems. Bioengineers engineers design devices used in various medical procedures, such as the computers used to analyze blood or the laser systems used in corrective eye surgery. They develop artificial organs, imaging systems such as magnetic resonance, ultrasound, and x-ray, and devices for automating insulin injections or controlling body functions. Most engineers in this specialty require a sound background in one of the basic engineering specialties, such as mechanical or electronics engineering, in addition to specialized biomedical training. Some specialties within bioengineering or biomedical engineering include biomaterials, biomechanics, medical imaging, rehabilitation engineering, and orthopedic engineering.

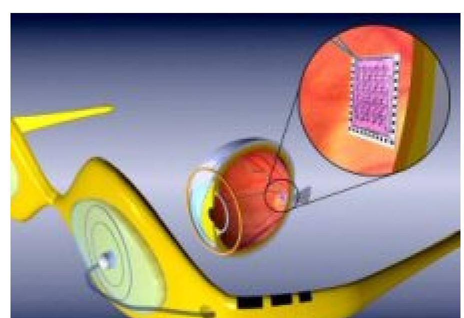
### Teams and Coworkers

Almost all jobs in engineering require some sort of interaction with coworkers. Whether they are working in a team situation, or just asking for advice, most engineers have to have the ability to communicate and work with other people. Engineers should be creative, inquisitive, analytical, and detail-oriented. They should be able to work as part of a team and to communicate well, both orally and in writing. Communication abilities are important because engineers often interact with specialists in a wide range of fields outside engineering.

### Tasks

Examples of work done by biomedical engineers include:

- designing and constructing cardiac pacemakers, defibrillators, artificial kidneys, blood oxygenators, hearts, blood vessels, joints, arms, and legs.
- designing computer systems to monitor patients during surgery or in intensive care, or to monitor healthy persons in unusual environments, such as astronauts in space or underwater divers at great depth.
- designing and building sensors to measure blood chemistry, such as potassium, sodium, 02, CO2, and pH.
- designing instruments and devices for therapeutic uses, such as a laser system for eye surgery or a device for automated delivery of insulin.



Retinal Prosthetic System Illustration (Jerry Lim) Credit: Intraocular Prosthesis Group, Johns Hopkins University and North Carolina State University

- developing strategies for clinical decision making based on expert systems and artificial intelligence, such as a computer-based system for selecting seat cushions for paralyzed patients or for, managing the care of patients with severe burns or for diagnosing diseases.
- designing clinical laboratories and other units within the hospital and health care delivery system that utilize advanced technology. Examples would be a computerized analyzer for blood samples, ambulances for use in rural areas, or a cardiac catheterization laboratory.
- designing, building and investigating medical imaging systems based on X-rays (computer assisted tomography), isotopes (position emission tomography), magnetic fields (magnetic resonance imaging), ultrasound, or newer modalities.
- constructing and implementing mathematical/computer models of physiological systems.
- designing and constructing biomaterials and determining the mechanical, transport, and biocompatibility properties of implantable artificial materials.
- implementing new diagnostic procedures, especially those requiring engineering analyses to determine parameters that are not directly accessible to measurements, such as in the lungs or heart.
- investigating the biomechanics of injury and wound healing.

## Specialty Areas

By combining biology and medicine with engineering, biomedical engineers develop devices and procedures that solve medical and health-related problems. Many do research, along with life scientists, chemists, and medical scientists, to develop and evaluate systems and products for use in the fields of biology and health, such as artificial organs, prostheses (artificial devices that replace missing body parts), instrumentation, medical information systems, and health management and care delivery systems.
Some of the well established specialty areas within the field of biomedical engineering are bioinstrumentation, biomechanics, biomaterials, systems physiology, clinical engineering, and rehabilitation engineering.

### ▶ Bioinstrumentation

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.

### ▶ Biomechanics

Biomechanics is mechanics applied to biological or medical problems. It includes the study of motion, of material deformation, of flow within the body and in devices, and transport of chemical constituents across biological and synthetic media and membranes. Efforts in biomechanics have developed the artificial heart and replacement heart valves, the artificial kidney, the artificial hip, as well as built a better understanding of the function of organs and musculoskeletal systems.

## Biomaterials

Biomaterials describes both living tissue and materials used for implantation. Understanding the properties of the living material is vital in the design of implant materials. The selection of an appropriate material to place in the human body may be one of the most difficult tasks faced by the biomedical engineer. Certain metal alloys, ceramics, polymers, and composites have been used as implantable materials. Biomaterials must be nontoxic, noncarcinogenic, chemically inert, stable, and mechanically strong enough to withstand the repeated forces of a lifetime.

## Systems Physiology

Systems physiology is the term used to describe that aspect of biomedical engineering in which engineering strategies, techniques and tools are used to gain a comprehensive and integrated understanding of the function of living organisms ranging from bacteria to humans. Modeling is used in the analysis of experimental data and in formulating mathematical descriptions of physiological events. In research, models are used in designing new experiments to refine our knowledge. Living systems have highly regulated feedback control systems which can be examined in this way. Examples are the biochemistry of metabolism and the control of limb movements.

## Clinical Engineering

Clinical engineering is the application of technology for health care in hospitals. The clinical engineer is a member of the health care team along with physicians, nurses and other hospital staff. Clinical engineers are responsible for developing and maintaining computer databases of medical instrumentation and equipment records and for the purchase and use of sophisticated medical instruments. They may also work with physicians on projects to adapt instrumentation to the specific needs of the physician and the hospital. This often involves the interface of instruments with computer systems and customized software for instrument control and data analysis. Clinical engineers feel the excitement of applying the latest technology to health care.

## Rehabilitation Engineering

Rehabilitation engineering is a new and growing specialty area of biomedical engineering. Rehabilitation engineers expand capabilities and improve the quality of life for individuals with physical impairments. Because the products of their labor are so personal, often developed for particular individuals or small groups, the rehabilitation engineer often works directly with the disabled individual.

These specialty areas frequently depend on each other. Often the bioengineer, or biomedical engineer, who works in an applied field will use knowledge gathered by bioengineers working in more basic areas. For example, the design of an artificial hip is greatly aided by a biomechanical study of the hip. The forces which are applied to the hip can be considered in the design and material selection for the prosthesis. Similarly, the design of systems to electrically stimulate paralyzed muscle to move in a controlled way uses knowledge of the behavior of the human musculoskeletal system. The selection of appropriate materials used in these devices falls within the realm of the biomaterials engineer. These are examples of the interactions among the specialty areas of biomedical engineering.

## Earnings

According to the US Department of Labor, Bureau of Labor Statistics, median annual earnings of biomedical engineers is $73,930. The middle 50 percent earned between $56,420 and $93,420. The lowest 10 percent earned $44,930, and the highest 10 percent earned $116,330.

## Employment


DNA fingerprinting. Credit: The University of Arizona

According to U.S. Department of Labor, Bureau of Labor Statistics, bioengineers hold about 14,000 jobs. This represents 0.9% of the 1.5 million jobs held by engineers in the U.S.

The medical equipment and supplies manufacturing industry employed about 20 percent of all biomedical engineers. Another 20% were employed in the scientific research and development services industry.
Biomedical engineers are employed in industry, in hospitals, in research facilities of educational and medical institutions, in teaching, and in government regulatory agencies. They often serve a coordinating or interfacing function, using their background in both the engineering and medical fields. In industry, they may create designs where an in-depth understanding of living systems and of technology is essential.

They may be involved in performance testing of new or proposed products. Government positions often involve product testing and safety, as well as establishing safety standards for devices. In the hospital, the biomedical engineer may provide advice on the selection and use of medical equipment, as well as supervising its performance testing and maintenance. They may also build customized devices for special health care or research needs. In research institutions, biomedical engineers supervise laboratories and equipment, and participate in or direct research activities in collaboration with other researchers with such backgrounds as medicine, physiology, and nursing.

Some biomedical engineers are technical advisors for marketing departments of companies and some are in management positions. Some biomedical engineers also have advanced training in other fields. For example, many biomedical engineers also have an M.D. degree, thereby combining an understanding of advanced technology with direct patient care or clinical research.

The following is a partial list of employers of Bioengineers:

- Abiomed
- Aethlon Medical
- Amgen Inc.
- Aperio Technologies, Inc.
- Applied Molecular Evolution
- Biomoda, Inc.
- Children's Hospital
- CryoCor, Inc.
- Curis, Inc.
- Elan Pharmaceuticals
- GeneOhm Sciences, Inc.
- Genomics Institute of the Novartis Research Foundation
- Genvault Corp.
- Genzyme Corp.
- Hospitals
- Inovio Biomedical Corporation
- Integra LifeSciences Corp
- Invitrogen Corporation
- La Jolla Pharmaceutical Company
- Lucent Medical Systems
- Merck Research Laboratories
- Molecular Medicine BioServices, Inc.
- National Institute of Biomedical Imaging and Bioengineering
- National Institute of Standards and Technology
- National Institutes of Health
- National Science Foundation
- National Science Foundation Division of Bioengineering & Environmental Systems
- MacroPore Biosurgery, Inc.
- Massachusetts General Hospital
- Mount Sinai Medical Center
- Protein Polymer Technologies, Inc.
- REVA Medical, Inc.
- Syncardia Systems, Inc.
- The Dow Chemical Company
- Tristan Technologies, Inc.
- Universities
- Vertex Pharmaceuticals

## Career Path Forecast

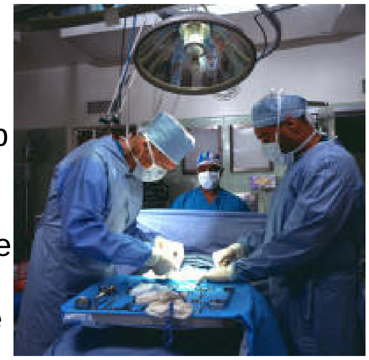

According to the US Department of Labor, Bureau of Labor Statistics, biomedical engineers are expected to have 21 percent employment growth over the period 2006-2016, much faster than the average for all occupations. The aging of the population and the focus on health issues will drive demand for better medical devices and equipment designed by biomedical engineers.

Along with the demand for more sophisticated medical equipment and procedures, an increased concern for cost-effectiveness will boost demand for biomedical engineers, particularly in pharmaceutical manufacturing and related industries.

However, because of the growing interest in this field, the number of degrees granted in biomedical engineering has increased greatly. Biomedical engineers, particularly those with only a bachelor's degree, may face competition for jobs. Unlike many other engineering specialties, a graduate degree is recommended or required for many entry-level jobs.

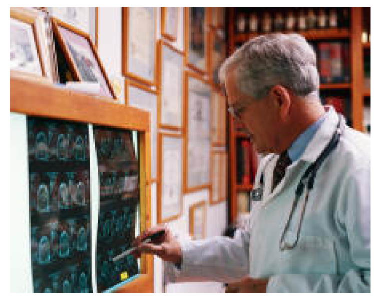
# Major Advances in Bioengineering

## Artificial Joints



In 1994, a National Institutes of Health Consensus Panel declared that total hip replacement is one of the most successful surgical procedures, providing immediate and substantial improvement in a patient's pain, mobility, and quality of life. More than 168,000 total hip replacements are performed each year in the United States, according to the American Academy of Orthopaedic Surgeons. THR involves removing diseased or damaged bone in the upper end of the thigh bone (femur) and the section of the lower pelvis into which the femur fits. The bone is then replaced with a prosthesis, usually made of a metal alloy or polyethelene (plastic) components. Successful replacement of deteriorated, arthritic, and severely injured hips has contributed to enhanced mobility and comfortable, independent living for many people who would otherwise be substantially disabled.

## Magnetic Resonance Imaging (MRI)



In 1952, the Nobel Prize in Physics was awarded for the discovery of nuclear magnetic resonance, which laid the groundwork for one of the most unique and important inventions in medical imaging since the discovery of the X-ray. Magnetic resonance imaging (MRI) is a method of looking inside the body without using surgery, harmful dyes or radiation. The method uses magnetism and radio waves to produce clear pictures of the human anatomy.  Although MRI is used for medical diagnosis, it uses a physics phenomenon discovered in the 1930s in which magnetic fields and radio waves, both harmless to humans, cause atoms to give off tiny radio signals. It wasn't until 1970, however, that Raymond Damadian, a medical doctor and research scientist, discovered the basis for using magnetic resonance as a tool for medical diagnosis when he found that different kinds of animal tissue emit response signals of differing length. He also discovered differences in response signals between cancerous and non-cancerous tissue, and among the response times of other kinds of diseased tissue.

## Heart Pacemaker

The invention and development of the heart pacemaker illustrates the merging of medicine and engineering. The device is a result of the collective efforts and collaboration of people and organizations from both engineering and medicine, and both public and private institutions. The pacemaker was the first electronic device ever surgically implanted inside a human. First developed in the 1960s, pacemaker typically refers to a small, battery-powered device that helps the heart beat in a regular rhythm. Small electrical charges travel to one or multiple electrodes placed next to the heart muscle. Originally pacemakers sent one steady beat to the heart through a single electrode. Today's pacemakers can sense when a heart needs help and delivers just the right amount and duration of impulse---sometimes through multiple electrodes---that maintain steady heart rate, even during physical activity. While most pacemakers today are permanent implants, some are used as temporary therapy for recovering heart patients.

## Arthroscopy

Arthroscopy is a surgical procedure orthopedic surgeons use to visualize, diagnose and treat problems inside a joint. The word arthroscopy comes from two Greek words, "arthro" (joint) and "skopein" (look), and literally means "to look within the joint." In an arthroscopic examination, an orthopedic surgeon makes a small incision in the patient's skin and then inserts pencil-sized instruments that contain a small lens and lighting system to magnify and illuminate the structures inside the joint. Light is transmitted through fiber optics to the end of the arthroscope that is inserted into the joint. By attaching the arthroscope to a miniature television camera, the surgeon is able to see the interior of the joint through this very small incision. The camera attached to the arthroscope displays the image of the joint on a television screen, allowing the surgeon to look, for example, throughout the knee -- at cartilage and ligaments, and under the kneecap. The surgeon can determine the amount or type of injury, and then repair or correct the problem, if necessary.

## Angioplasty

In 1977 in Zurich, Switzerland, a young German physician named Andreas Gruentzig inserted a catheter into a patient's coronary artery and inflated a tiny balloon, opening a blockage and restoring blood flow to a human heart. Today more than 1 million coronary angioplasties are performed each year worldwide, making it the most common medical intervention in the world. Although this procedure was first envisioned as simply an alternative to open heart bypass surgery in only a handful of patients, today angioplasty accounts for more than half of the treatments for coronary artery disease. Biomedical engineering and advances in technology have not only optimized basic balloon angioplasty, but also added the use of stents, lasers and other interventional devices that restore normal blood flow while minimizing damage to the heart muscle.

## Bioengineered Skin

The burgeoning field of tissue engineering promises to be one of the most significant biomedical areas of the new century. The hope is that, eventually, whole organs could be manufactured to replace those that are injured or diseased. The field's first contribution to health care took a big step toward fulfilling these promises by producing artificial version of the body's largest organ, skin. Skin is a difficult organ to transplant because of its inherently strong immune defense system. Nevertheless, it has a relatively simple structure, making it a good testing ground for the talents of tissue engineers. Patients can have skin made to order that combines collagen as a binder with living human cells. This is placed onto a wound, usually a chronic ulcer or a burn, and its cells become activated and gradually integrate with those of the patient.

## Kidney Dialysis

In the United States, one in 16 people, or about 17 million, are at risk for kidney disease. More than 300,000 Americans currently live with chronic kidney failure resulting from disease, birth defect or injury. Virtually all these patients would die if not for the aid of ongoing kidney dialysis. Kidney dialysis artificially filters and removes waste products and excess water from blood, a process normally performed by the kidneys. Although often referred to as an artificial kidney, kidney dialysis is not a cure. The procedure can, however, give damaged kidneys a rest and a chance to recover normal function, or be used until the patient receives a transplant. For many patients, kidney dialysis is a way of life. Kidney dialysis was first developed by a

Dutch physician, Willem Kolff, M.D., Ph.D. In the early 1940s, he began searching for a way to use dialysis, the process by which particles pass through a membrane, to treat patients with kidney failure. A sever shortage of materials due to the war forced Kolff to improvise, especially when it came to a suitable membrane, the key component to the filtering process. Now, as the number of dialysis patients continues to grow at a rate of about 7 percent annually, and because costs for dialysis care are already more than $11 billion in the United States alone, research to find more efficient, low-cost methods of treatment remains a priority for biomedical engineers. Current efforts include not only improving the components of dialysis, such as better dialysates and membranes, but also developing alternatives to dialysis, such as a true artificial kidney, xenotransplantation, and replacement kidneys through tissue engineering.

### Heart-lung Machine

One of the truly revolutionary pieces of medical equipment has been the invention and development of the heart-lung machine. Before its introduction to medicine in the 1950s, heart surgery was unheard of; there was no way to keep a patient alive while working on the heart. Today, about 750,000 open-heart procedures are performed each year. During an open-heart surgery, such as bypass surgery, the heart-lung machine takes over the functions of the heart and lungs and allows a surgeon to carefully stop the heart while the rest of the patient's body continues to receive oxygen-rich blood. The surgeon can then perform delicate work on the heart without interference from bleeding or the heart's pumping motion. Once the procedure is over, the surgeon restarts the heart and disconnects the heart-lung machine.

## Professional Organizations

Professional organizations and associations provide a wide range of resources for planning and navigating a career in Bioengineering. These groups can play a key role in your development and keep you abreast of what is happening in your industry. Associations promote the interests of their members and provide a network of contacts that can help you find jobs and move your career forward. They can offer a variety of services including job referral services, continuing education courses, insurance, travel benefits, periodicals, and meeting and conference opportunities. The following is a partial list of professional associations serving bioengineers.

- American Institute of Medical and Biological Engineering (www.aimbe.org)
- American Society of Mechanical Engineers, Bioengineering Division (http://divisions.asme.org/bed/)
- Biomedical Engineering Society (www.bmes.org)
- Danish Society for Biomedical Engineering (www.dmts.dk/default-uk.htm)
- European Society for Engineering in Medicine (www.esem.org)
- Howard Hughes Medical Institute (www.hhmi.org)
- IEEE Engineering in Medicine and Biology Society (http://129.94.131.101/embs/)
- Institute of Biological Engineering (www.ibeweb.org)
- Institute of Biomedical Science (www.ibms.org)
- International Federation for Medical & Biological Engineering (www.ifmbe.org)
- International Society for Bioengineering and the Skin (www.i-s-b-s.org)
- The Canadian Medical & Biological Engineering Society (www.cmbes.ca)
- The Merck Genome Research Institute (www.mgri.org)
- Whitaker Foundation (www.whitaker.org)