Introduction

The practice of medicine has changed dramatically since you were born. Consider a few of these changes, some of which have undoubtedly affected your own life: Couples can test for pregnancy in their homes, a new vaccine is available for chicken pox, inexpensive contact lenses provide clear vision, artificial hips allow recipients to walk and run, ultrasound imaging follows the progress of pregnancy, and small reliable pumps administer insulin continuously for diabetics.

People are living longer because they are not dying in situations that were previously fatal, such as childbirth and bacterial infections. The growth of biomedical engineering is a major factor in this extension of life and improvement of health. Biomedical engineers have contributed to every field of medicine, from radiology to obstetrics to cancer treatment.

Accidents and trauma are major causes of death and disability around the world, victims often have internal injuries, which are life threatening but not easy to diagnose by visual observation. Emergency room treatment has improved enormously over the past few decades, chiefly due to advances in the technology for looking inside of people quickly and accurately. Ultrasound imaging, which can provide pictures of internal bleeding within seconds, has replaced exploratory surgery and other slower, more invasive approaches for localization of internal injuries. Old ultrasound imaging machines weighed hundreds of pounds, but new instruments are smaller and lighter, some weighing only a few pounds, making it possible to get them to the patient faster. Other imaging technologies have also improved: Helical computed tomography (CT) scanners produce rapid three-dimensional internal images of the whole body, and new magnetic resonance imaging (MRI) techniques can reveal the chemistry, not just the shape, of internal structures. As a result of faster and better diagnosis of internal injuries, more accident victims are saved today.

In the near future, emergency medicine providers will probably use ultrasound imagers that are small enough to be carried in a pocket and inexpensive enough for every physician to own, like a stethoscope is today. Reduction in size and cost will surely save the lives of more accident victims. A pill-sized sensor is already available that patients can swallow; it continuously reports internal temperature as it passes through the intestinal tract. In the future, similar devices will probably be used to report other internal conditions such as sites of bleeding or abnormal cells. Further in the future, these small devices will be guided to specific locations in the body, where they can initiate repair of disease that is deep within the body. Innovations produced by biomedical engineers are saving lives once lost to kidney failure, improving eyesight lost to disease and aging, and producing artificial hips, knees, and hearts.

What is biomedical engineering?

Biomedical Engineering (BME) or **Medical Engineering** is the application of engineering principles and design concepts to medicine and biology for healthcare purposes (e.g., diagnostic, or therapeutic). Also included under the scope of a biomedical engineer is the management of current medical equipment within hospitals. 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 MRI and electrocardiography (ECG), regenerative tissue growth, pharmaceutical drugs, and therapeutic biologicals (Figure 1.1).

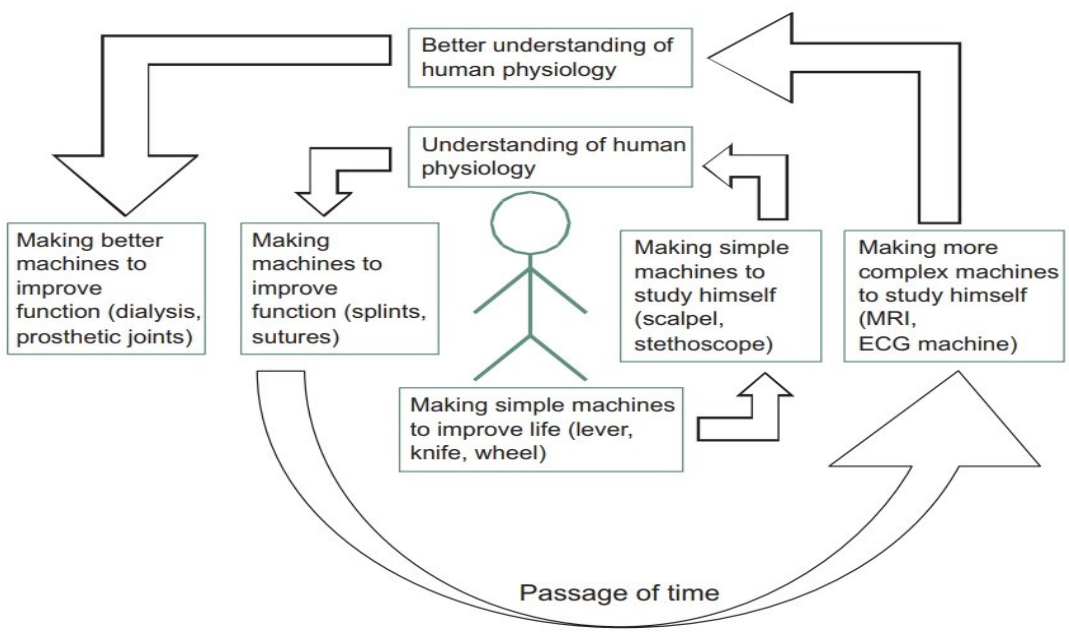

Figure 1.1: Advances in biomedical engineering

Biomedical engineers study a variety of different kinds of problems related to human health (Table 1.1).

Table 1.1: Subdisciplines of biomedical engineering

Subspecialty	Examples
Systems biology and Bioinformatics	Modeling of cellular networks DNA sequence analysis Microarray technology
Physiological modeling	Physiology of excitable cells Dynamics of the microcirculation Models of cellular mechanics Pharmacokinetic models of chemotherapy drugs
Biomechanics	Gait analysis Prosthetic joints and limbs Cellular mechanics
Biomedical instrumentation and Biomedical sensors	Electrocardiogram Cardiac pacemaker Glucose sensor O_2 sensor pH sensor
Biomedical imaging	Radiographic imaging Ultrasound imaging Magnetic resonance imaging Optical imaging
Biomolecular engineering and Biotechnology	Drug-delivery systems Artificial skin (tissue engineering) Protein engineering Chromatography and other separation methods Vaccines
Artificial organs	Biomaterials Hemodialysis Artificial heart

Engineering in modern medicine

The work of engineers is to make technology possible, and then to make that technology reliable and inexpensive enough to influence people throughout the world. Medical technology is one of the most visible aspects of the modern world. The modern medicine is built on innovations in biomedical engineering. It is engineers who transfer scientific knowledge into useful products, devices, and methods.

Whole-organ transplantation, such as the first heart transplant in 1967, could not occur until there were machines to sustain life during the operation, tools for the surgeons to operate with and repair the wounds they created, and methods for preserving organs during transport.

Clinical testing of vaccine, could not happen without the engineering methods to cheaply produce the vaccine in large quantity. The Human Genome Project would have not been possible without automated machines for deoxyribonucleic acid (DNA) sequencing.

Medical technology has also invaded our homes, every home has a thermometer, specially designed to permit the recording of body temperature. The home can be easily equipped to be a screening center for high blood pressure, high cholesterol, glucose monitoring, pregnancy, and ovulation prediction.

In addition, medical technologies have entered our bodies. Many people now elect to use contact lenses instead of eyeglasses; this change has resulted from the development of materials that can remain in contact with the eye for extended periods without causing damage. Artificial joints and limbs are common, as are artificial heart valves; synthetic components, usually metals and polymers, are fashioned into implantable devices that can replace the function of the human skeleton.

Bonding between atoms and molecules

All basic life processes that allow us to digest food, move, and grow involve chemical reactions: reactions that yield energy, build new molecules, or break down unneeded molecules. The molecules in our body are involved in thousands of chemical reactions.

Atomic bonding

There are two types of bonds that can be formed between atoms: ionic and covalent bonds. Ions are molecules with a net charge, either positive or negative. **Ionic bonds** are formed when electrons are transferred from one atom to another (e.g., $Na^{+}Cl^{-}$). This transfer results in two ions: a positively charged molecule, or cation, caused by the loss of electrons, and a negatively charged molecule, or anion, caused by the gain of electrons. **Covalent bonds** result from the sharing of electrons (e.g., H2). Covalently bonded molecules can further be classified as polar or nonpolar (Figure 1.2).

Biomedical engineers are frequently involved in synthesis of new molecules for medical applications. One example is dendrimers for gene delivery, which is the act of transferring foreign DNA into a cell. These new agents are created by the formation of new covalent bonds between simple precursor molecules.

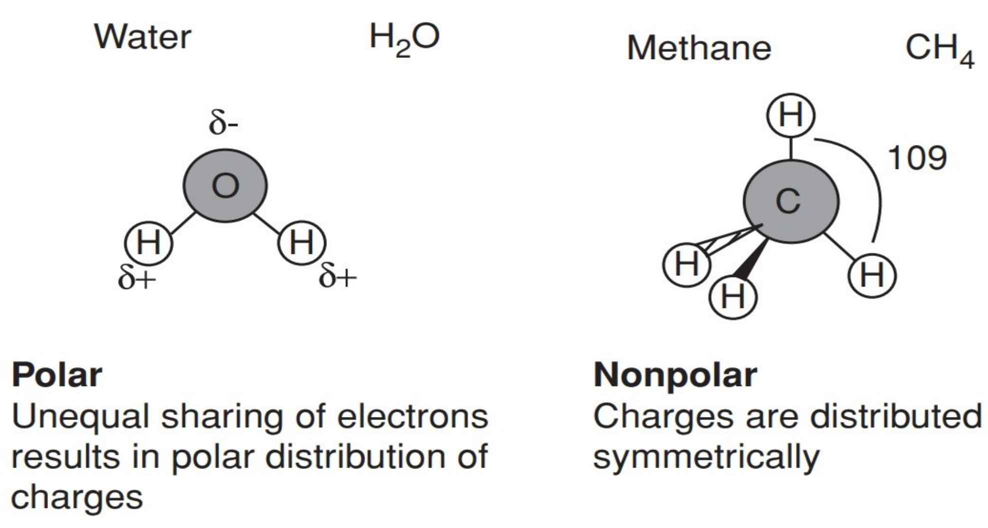

Figure 1.2: Polar and nonpolar molecules. Water is an example of a polar molecule. The unequal sharing of electrons between oxygen and hydrogen atoms creates a distribution of charge, which creates electrical polarity. The oxygen atom has a partial negative charge (δ−), whereas the two hydrogen atoms are partially positive (δ+). Methane is a nonpolar molecule because the charges are distributed equally; the hydrogens are arranged with equal three-dimensional spacing, each separated by an angle of 109◦. The symbol δ indicates a partial charge.

Molecular bonding

Two molecules can be weakly attracted to one another through intermolecular forces. These forces may include van der Waals interactions and hydrogen bonding.

Hydrogen bonding occurs when a partially positive hydrogen atom in a polar molecule is attracted to a slightly negative atom (usually O, N, or F) in a neighboring molecule (Figure 1.3). Hydrogen bonds are much weaker than covalent bonds.

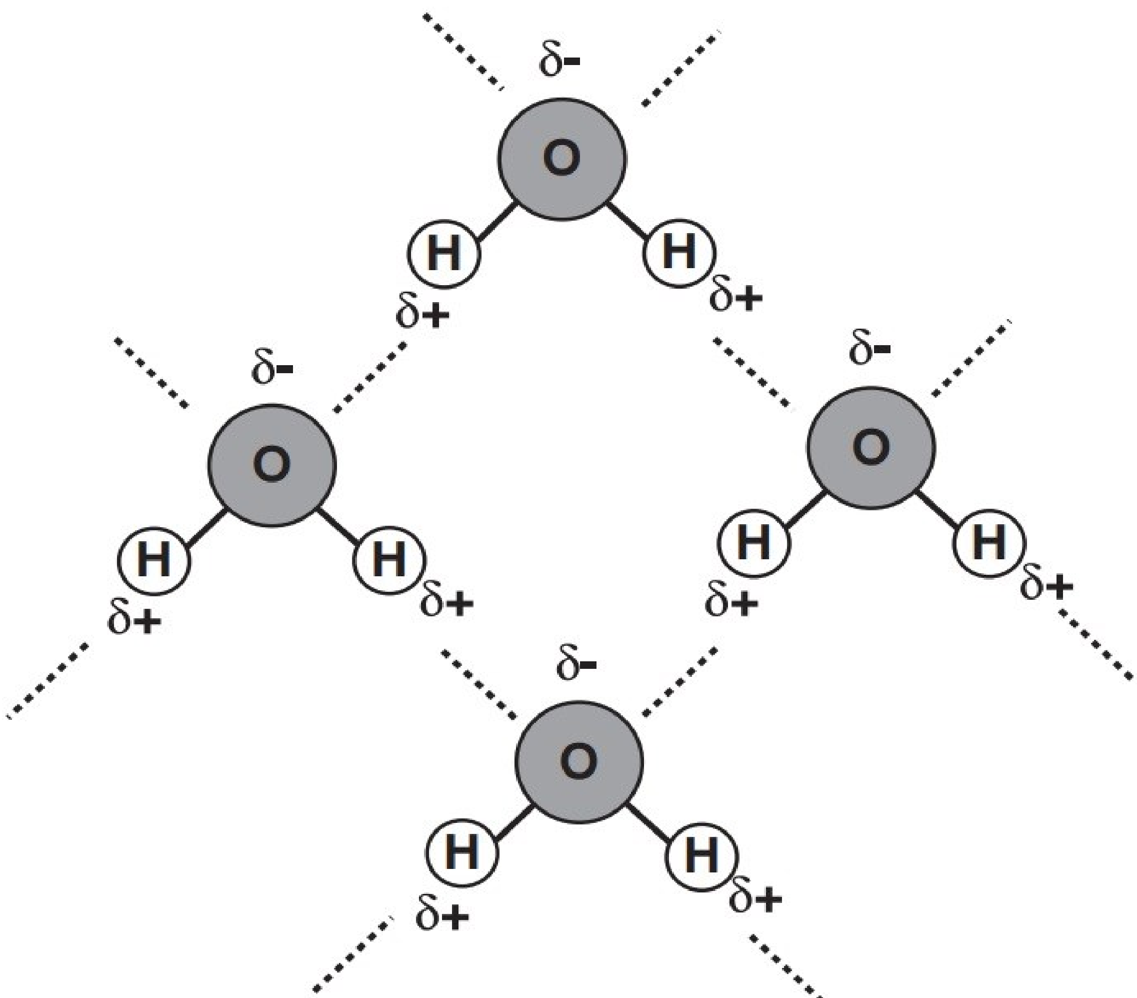

Figure 1.3: Hydrogen bonding. Polar water molecules can form hydrogen bonds with each other. Partial positive hydrogen atoms in one water molecule are weakly attracted to partial negative oxygen atoms in another water molecule.

Van der Waals interactions are also weak non-covalent attractions but they are due to temporary and unequal electron distributions around atoms rather than the permanent dipole found in hydrogen bonded atoms.

Water: The medium of life

The chemical reactions that drive life occur predominantly in aqueous or water rich environments, for this reason, water is often called "the source of life". Three atoms, two hydrogens and one oxygen are held together by covalent bonds to form water. Water can be a product or a reactant in other chemical reactions. Because the human body is approximately 70% water, it is the ideal environment for these reactions. The extensive hydrogen bonding network that can form between water molecules gives rise to its unique properties. These properties include high melting and boiling temperatures, high surface tension, and a higher density than ice.

The ability to form hydrogen bonds also makes water an excellent solvent. Water can easily dissolve ions or other polar molecules that are capable of forming hydrogen bonds. These water-soluble molecules are referred to as hydrophilic ("water loving"). Nonpolar molecules are not easily dissolved in water and are called hydrophobic ("water fearing"). Molecules that contain both hydrophilic and hydrophobic groups are called amphiphilic, for example, phospholipids are amphiphilic molecules that form the plasma membrane surrounding cells.