Introduction

Better Living through Biomedical Engineering

Medical technology has come a long way over the last several decades. CT, MRI, and ultrasound machines produce stunning images of your vital organs. Implantable defibrillators intervene when your heart rhythm goes haywire. Teletherapy machines use invisible rays to destroy tumors. Another type of machine takes over for your heart and lungs so that a surgeon can make repairs. If you go deaf, a cochlear implant may restore your hearing. Need a new knee joint? No problem.

And best of all, the era of life saving and enhancing medical technology is just getting started.

I've been interested in the history of technology for a long time, having worked in the high-tech industry for 30 years. I wanted to know more about the evolution of modern medical technology, and I was surprised that I couldn't find a comprehensive history. There are many books on the history of medicine, but few books that explain how today's wonderful medical technologies were created. So I decided to research and write such a book.

There is so much great medical technology that I had to cast a wide net. The book encompasses microscopes, endoscopes, x-ray machines, CT scanners, ultrasound imaging, magnetic resonance imaging, pacemakers, defibrillators, nuclear medicine, the heart-lung machine, kidney dialysis, artificial hip joints, brain-computer interface chips, laser surgery, and much more.

But I also had to set some boundaries. This book focuses on systems, instruments, and devices—the mechanical and electrical stuff. Pharmaceuticals and genetic engineering are also great medical technologies, but they are a different story for another book. I applied a simple test: If it contains a microprocessor, can communicate via the Internet, or has moving parts, it is probably in this book. If you take it orally one hour before meals, it probably isn't.

I also drew a line between modern and primitive medical technology. This book is for anyone who wants to know how we got to where we are today and how medical technology is likely to evolve in the next several years. The narrative chronicles discoveries and inventions with long-lasting impact; this is not a book about medieval bone saws and tooth extractors.

I drew one more boundary. This is not one of those esoteric histories for historians. My target audience is consumers, health care professionals, and investors who want to learn how we came to discover the causes of disease, develop powerful diagnostics, and invent effective therapies. My purpose is to inform and inspire by concentrating on the most important figures and events—not ask readers to trudge through minutiae.

The history of medical technology is a confluence of three distinct streams: the history of biological research, the history of clinical practice, and the history of the health care industry. I must warn readers that much of the research described in the following pages was performed on laboratory animals. They—along with the human patients who agreed to undergo experimental procedures—are the unsung heroes of modern medicine.

Many people feel that making profits and saving lives don't mix. I concede that there are legitimate ethical concerns. However, there's also wisdom in the saying "Don't throw the baby out with the bath water." Businesses have done a good job identifying patient and health care provider needs, adapting new technology to serve those requirements, and figuring out the best way to package and distribute the technology to ensure it gets in the hands of the right people in a form that they can use.

The first decision for anyone writing a history is deciding where to begin. A history of medical technology could begin with the ancient physicians. Or it could begin at some arbitrary starting point, such as the year 1900.

I chose to start with the invention of the microscope. Though introduced at the same time as the telescope, the microscope was practically ignored. The telescope could be used to sight approaching ships, spy on enemy armies, and explore the heavens. The microscope could only be used to examine objects already in hand. Plus, early microscopes produced terribly distorted images and no one had a clue that there was a living microcosm awaiting discovery. Antony Leeuwenhoek, a Dutch draper, was the first person to observe protozoa and bacteria.

Chapter Two shows how the microscope spurred the development of experimental medicine and the germ theory of disease. Today, those ideas seem obvious. Prior to 1850, physicians could do little to cure diseases; many created and maintained an aura of authority by spouting bizarre theories. A new generation of scientists—led by Claude Bernard in France and Hermann Helmholtz in Germany—put medicine on a more solid footing. Louis Pasteur, Robert Koch, and Joseph Lister took the ball and ran with it.

The germ theory of disease encountered fierce resistance. In part, it was because it was difficult to prove that microbes cause disease. But it was largely because physicians did not want to admit that they had unknowingly been spreading diseases. Eventually the body of evidence grew too large to ignore. Vaccines were developed, public sanitation was improved, and aseptic surgery became accepted.

For medicine to advance to the next level, physicians needed some way to see inside the body. Chapter Three chronicles the evolution of endoscopy, the discovery of x-rays, and the progression to computed tomography—the technology behind the CT scanner.

Other diagnostic tools paved the way to timely and effective interventions. Chapter Four describes how Willem Einthoven perfected the electrocardiogram—and how it spawned tools for mapping and even repairing the heart's electrical system.

Today, getting an artificial pacemaker is a relatively minor procedure. Chapter Five explains how medicine slowly advanced beyond helplessly watching patients with dangerously slow heartbeats die. External pacemakers—intolerable to most patients—came first. Pacemakers requiring major surgery came next; the cure was almost as bad as the disease. The discovery that pacemaker leads could be threaded through the veins made it all worthwhile.

Magnetic resonance imaging (MRI) added a new dimension to diagnostic imaging. Chapter Six describes how a series of discoveries led to what one inventor called "wireless chemistry." To get there, physicists first had to learn how to make atomic nuclei dance in unison.

Radioactivity is rightly feared. But when used with proper caution, radioactivity is a powerful diagnostic and therapeutic tool. Chapter Seven chronicles the beautiful experiments of Ernest Rutherford and the incredible perseverance of Marie Curie—and how their work led to PET scanners, the Gamma Knife, and proton accelerators.

Physicians also found ways to exploit sound waves. Chapter Eight describes the development of the stethoscope and blood pressure monitor—both of which depend on listening. Decades later, a device developed to detect icebergs and enemy submarines was modified to produce images of the beating heart and even measure the flow of blood through the heart's chambers and valves. Ultrasound is another powerful diagnostic tool that has also found therapeutic uses.

Chapters Nine and Ten describe how physicians learned to repair, replace, and assist failing organs. To get there, doctors had to develop the habit of keeping accurate records and analyzing the data. First they discovered they could replace blood—but only if they followed certain rules. An unlikely trio—John D. Rockefeller, Charles Lindbergh, and Alexis Carrel—paved the way for John Gibbon's heart-lung bypass machine.

That brings us to some of the cowboys of medicine: colorful figures such as Werner Forssmann, Andreas Gruentzig, and Christian Barnard. Forssmann experimented on his own heart. The flamboyant Gruentzig found a simpler and safer method (compared to coronary artery bypass graft surgery) to clear clogged arteries. The equally flamboyant Barnard performed the first successful heart transplant. Less well known, Willem Kolff invented kidney dialysis and pioneered the artificial heart.

The success of the cochlear implant gives us reason to be optimistic that we will one day restore vision to the blind. A versatile biological material, small intestine submucosa (SIS), has demonstrated an almost magical ability to replace and even regenerate natural tissues.

Ophthalmology has its own story, told in Chapter Eleven. A series of discoveries—some of them accidental—led to laser-based vision correction surgery, implantable lenses, and new ways to treat sight-threatening disorders such as detached retinas, glaucoma, and age-related macular degeneration.

Dentists are also not to be ignored. As explained in Chapter Twelve, it was a dentist who invented safe and effective anesthesia—benefiting the entire medical profession. Dentists also pioneered body part replacement.

Computers and communications have become ubiquitous in health care. As Chapter Thirteen shows, we are getting our first glimpse of what devices and networks can do. Doctors are accessing diagnostic scans via smartphones. Patients and their families are finding specialists via the Internet. Wireless devices keep patients in touch with their health care providers and advisors. Personal health records enable patients to take a more active role in their own health care.

A note about terminology: I use plain language as much as possible, referring to the official medical terminology only when necessary. Modern medicine is brimming with jargon, and it can be intimidating. However, there is no way to completely avoid technological jargon, so I've included a glossary of terms used in the book.

The sources of this work include not only books and journal articles, but interviews with pioneering physicians, lectures, videos, and tours of research labs.

Medical technology can work wonders. That's not to say, however, that modern medicine is perfect. Success breeds complacency—or at least over-reliance on the same set of procedures and tools. But even when you add all of the minuses to the plusses, we as patients still come out way ahead.

Chapter One
The Hidden World

Little more than a century ago, life was a minefield of illness and injury. Women died giving birth, children succumbed to contagious diseases, and a compound fracture—a break in the skin as well as the bone—could prove fatal. You were lucky if you survived to age 40. Now we are living twice as long. We can prevent and cure diseases, and repair and replace many body parts.

How was this radical makeover achieved? The history of medicine is usually described as the slow accretion of knowledge over hundreds of years, punctuated in the late 20th century by the sudden convergence of engineering and biology. The only problem with that narrative is that it misses the two factors most responsible for the development of clinically effective medicine: an epochal invention and a scientific rebellion.

Ironically, that invention was nearly overlooked. While it would enable not only modern medicine but all of the life sciences, it languished in the shadow of a related invention. In the late 16th century, natural philosophers discovered that certain combinations of glass lenses could be used to make distant objects appear closer. The military, commercial, and religious implications of the telescope—sizing up enemy armies, spotting approaching merchant ships, and surveying the heavens—were immediate and stunning. Use a different configuration of lenses, and the very small could appear larger, but that seemed merely a clever technical trick. Its military implications were hard to imagine, and its commercial implications—a customer's ability to magnify flaws—were hardly welcome.

The microscope's benefits—if there were any—were unclear. But that wasn't the only thing that was unclear. Early telescopes and compound microscopes produced notoriously fuzzy and distorted images. By the 1660s, Isaac Newton demonstrated a "reflecting telescope" that, at least in theory, eliminated most of the distortion. Unfortunately, there was no "reflecting microscope" in the offing. Almost two centuries would pass before low-distortion microscopes appeared.

As often happens, the individuals who did the most to prove and improve the technology labored outside the scientific mainstream. A hobbyist named Antony Leeuwenhoek was the first to discover a miniature world teeming with life. And it wasn't a fluke. He continued making historic discoveries while others scrambled just to replicate his latest finds.

When microscope images finally became sharper and truer in 1829—mainly thanks to the work of another hobbyist, Joseph Jackson (J.J.) Lister—there was still a fog in front of physicians' eyes. Sciences such as physics and chemistry were advancing by leaps and bounds. But medicine seemed immune to progress. Two thousand years after Hippocrates, physicians still attributed health to a proper balance of humors. There was little knowledge of physiology and no one understood the role of microorganisms in disease processes. Working in the 18^{th} century, a leading English physician attributed bacterial infections to factors such as a "delicate constitution" and weather that was "excessively wet and rainy and moist and cold with Westerly winds." Purging and bleeding remained the treatments of choice.

J.J. Lister's ingenious invention (the achromatic microscope) made it possible to see the finest details of cells and tissues—both healthy and diseased. It was no longer necessary to speculate about hidden causes. Armed with Lister's innovations, scientists in Germany and France rebelled against the medical establishment. In less than two decades, the two millennia old idea that health hinges on a balance of humors was abandoned. The new science of experimental physiology was in, much of it microscope-driven.

By the late 1800s the microscope blossomed as a clinical research tool. Specific disease-causing microorganisms were finally being identified, replacing centuries of misinformation and old wives' tales with accurate etiology. Optical microscopes evolved to magnify objects up to 1,500 times with 0.25 micron resolution. (There are roughly 25,000 microns to an inch.) Limited by the wavelength of visible light, optical microscopes were pressing against a performance ceiling.

Scientists in the 20^{th} century circumvented the performance ceiling with maneuvers resembling American football "end runs." Having discovered that beams of electrons behave like light rays, they used electric and magnetic fields to create virtual lenses, and magnified objects more than one million times their size—enough to visualize molecules and even atoms. The inner working of cells, including their genetic machinery, could now be observed in freeze frame video.