Near the end of his life, Fernando Menendez made a final request of his son George. “Go in and get a physical,” he said. “Do that for me.”

The younger Menendez, a 60-year-old information-technology professional in Monmouth County, New Jersey, complied with his father’s request. As he tells it, he really had no choice. “My father had lung cancer, and he and my wife, Alane, had been after me for a while to go in for a physical,” he recalls. Menendez admits he’d procrastinated in scheduling an appointment with his physician, but his family was persistent; his father’s last request was the impetus to finally get it done. “I said, ‘Dad, I’ve been negligent. I’ll do that for you.’ And I did.”

That final act of filial respect might have saved Menendez’s life.

Blood tests revealed that Menendez had higher than normal levels of PSA, or prostate-specific antigen, an indication that he might have prostate cancer. A biopsy
confirmed the diagnosis, and with his life on the line, Menendez weighed his options.

Different physicians suggested different courses of action. These ranged from taking a wait-and-see approach to treating the prostate with radiation, to removing the organ altogether. Not particularly satisfied with any of the alternatives presented to him, Menendez and his wife kept searching until they consulted with physicians at the ProCure Proton Therapy Center in Somerset, New Jersey.

The doctors there recommended a new approach to treatment, an approach that targeted the cancer with a tightly focused beam of protons. Because protons are charged particles—they carry a positive charge—the negative charges in the body’s molecules slow them down at a rate that can be determined quite precisely. All it takes, really, is an abundance of raw computing power, which is readily available today. The precisely targeted proton beam disrupts the DNA in the cancer cells while causing little or no damage in the surrounding tissue.

Menendez decided that, for him, proton therapy represented the best option. He went in for his first treatment in May 2012 and finished the course of treatments in June. A month after his last treatment, tests showed that his PSA level had dropped a full point.

“I feel like I won the lottery,” Menendez says. “Yeah, I had a little bit of cancer. But I wound up being in the right place at the right time, with the right technology being available.”

Technology has, of course, always played an important role in the practice of medicine. But as Menendez’s experience illustrates, here in the 21st century, technology has essentially transformed the medical profession. Physicians today have access to an array of tools that gives them an unprecedented ability to diagnose and treat their patients’ medical conditions.

Dr. Eric Topol, director of the Scripps Translational Science Institute in La Jolla, California, and author of *The Creative Destruction of Medicine: How the Digital Revolution Will Create Better Health Care* (Basic Books, 2012), has described this intersection of science, technology and medicine as a “superconvergence.”

“It’s the bringing together of a digital infrastructure that consists of many things,” Topol explains. “There’s mobile connectivity and the remarkable bandwidth of the Internet, social networking, cloud computing and supercomputing. These things are converging with new tools on the medical side—things like genomics, wireless medical devices and sensors, and imaging devices. We’re bringing the digital infrastructure together with medical tools that only recently became available. It’s quite unique. There has been no bigger convergence that I know of in the history of our species.”

The proton therapy used to treat George Menendez’s prostate cancer, for example, is possible because physicians now have the computing power to calculate where the protons are going and where they’re going to stop. But this
information would be useless if they didn’t also have access to modern imaging technology—CAT scans, PET scans and MRI images—that tell them exactly where the tumor is located.

This fortuitous convergence of diverse technologies is responsible for breakthroughs in genomics, robotics, prosthetics and microbiology, and these in turn translate into effective treatments for diseases and conditions once thought to be incurable. Long-held beliefs about the practice of medicine are rapidly falling by the wayside.

“The devices are coming together with the therapeutics, and those are coming together with the diagnostics,” says Dr. Sheldon Schuster, president of the Keck Graduate Institute of Applied Life Sciences in Claremont, California. “It’s going to be difficult at some point to distinguish one from the other. I don’t think we know yet what it’s all going to look like ultimately. But what an exciting time!”

A complete catalog of recent advances in medical technology would fill a library. But the following represent some of the most exciting examples of where the field is going.

**Imaging Technology**

When a person is sick or injured, one of the first things the physician must do is find out where the problem is and what it looks like. Modern imaging technology pierces the veil. The devices can be as simple as the scope used in a common colonoscopy, or as complex as the functional MRI technology used to monitor real-time activity within the brain, but the key to all of these technologies is that they’re minimally invasive. Physicians can gather enormous amounts of information about their patients while the patients themselves experience little or no discomfort.

At the Beckman Laser Institute & Medical Clinic at the University of California, Irvine, researchers are working on a number of promising laser-based imaging technologies. One of these, the Laser Breast Scanner, is being developed by BLI director Dr. Bruce Tromberg and a team of colleagues including fellow BLI researcher Albert Cerussi. The LBS differs from traditional mammograms because it uses a phenomenon called photon migration to provide quantitative information about a tumor’s metabolic “fingerprint.” This fingerprint can be used to provide detailed information about the nature of the tumor and how it is responding to treatment. This information is important, says Tromberg, because it not only facilitates the detection of cancer in women with dense breast tissue, but it also gives the oncologists the ability to decide on a course of chemotherapy based on the tumor's response to treatment.

“Chemotherapy just doesn’t work for about 20 percent of patients, and nobody knows exactly why,” Tromberg elaborates. “Our idea is that an oncologist could have something the size of a smartphone in their pocket at the bedside to check out their cancer patients’ tumors to see if they’re responding to chemotherapy. Or they could scan them before they go into chemotherapy to say, ‘OK, this is the type of tumor that you’ve got. It’s likely to be responsive to this and not that.’ Certainly, after the patient gets her dose, we want to be able to tell the oncologist early on if the tumor is responding or if they need to change the chemotherapy concept. And the concept is extendable to radiation therapy, and so forth.”

Tromberg notes that the theoretical work on this project began in 1990. At the time, the machinery required to acquire the images filled an entire room. Now the device, which is undergoing clinical trials, is about the size of an external hard drive.

“It took many years for us to get a basic understanding of the phenomenon and build the prototypical instrumentation,” he says. “But we engineered things and put them on carts and on wheels to bring them to clinics. We had to figure out how to build patient interfaces and then figure out the meaning of the patient data.”

The evolution from room-size instrumentation to something that could fit in an oncologist’s hands was a long and
labor-intensive process. But that, according to Tromberg, is the essence of his job.

“There are generally about 20 to 25 years of research invested in new concepts and technologies before you actually see widely used, successful medical devices out in public,” he explains. “About half of that time might include fundamental, hard, basic research, while the rest is spent on technology standardization and translation to the clinic. Along the route, many things will fail. You don’t just turn on a light switch and something like MRI suddenly appears.”

**Neural Prosthetics**

In Gene Roddenberry’s *Star Trek: The Next Generation*, Commander Geordi LaForge was a blind starship officer whose sight was restored through the use of a prosthetic “visor.” That was not such a difficult concept to accept in the science fiction of the late 1980s. But it was just that: science fiction.

Today, a team of researchers at the Keck School of Medicine at the University of Southern California is demonstrating that Roddenberry’s reputation as a prognosticator can be challenged only because he missed the mark on this innovation by some 300 years.

Dr. Mark Humayun—professor of ophthalmology, biomedical engineering, and cell and neurobiology at the Doheny Eye Institute at USC, working closely with a team of academicians from different universities as well as Second Sight Medical Products—has created a device that literally restores eyesight to the blind. Reduced to its simplest elements, the device consists of a wearable component—a camera and some sophisticated electronics in an ordinary pair of sunglasses—and an implantable component that includes processing and stimulating electronics.

“There is a very small camera, like the camera in your iPhone,” explains Humayun, whose own grandmother went blind while he was attending medical school. “This camera is in the glasses and is connected to a belt-worn visual-processing unit with a small rechargeable battery. These wearable components send both power and data, transmitted wirelessly to the implant in the eye. The implantable electronics receive the information from the camera and convert it to electrical pulses, to stimulate the blind retina via a flexible electrode array. When this information is sent to the brain, it effectively hooks up the otherwise blind eye to the camera.”

Humayun notes that the key here is the condition of the optic nerve—if the nerve has been severed, there is no pathway into the brain. But as long as this nerve is even partially intact, electrical impulses can be successfully transmitted from the device to the brain.

One of the greatest challenges faced by Humayun and his team is the difficulty of converting the digital signals sent by the camera into analog data that the brain can successfully interpret as images. Humayun describes the process as a “multivector space problem.”

“The hardest part is breaking the Morse Code,” he says. “You have to take amplitude frequency, pulse width, all of these different parameters, and you have to play with them until you get the signal that the brain is waiting to hear. You pipe in the wrong signal and the image doesn’t come out. And between patients there is some variability. So you have to customize it to some degree for each patient.”

Creating systems that could not only bridge this gap between mind and machine but also function in the human body was a monumental undertaking. Humayun notes that his team included experts in a dozen different
fields, including neurobiology, electrical and mechanical engineering, materials science, neurochemistry, neurophysiology and electrophysiology.

“As a surgeon and an engineer, I am able to work with the team to develop a safe and effective retinal implant,” he adds. “However, after the surgery, we need the involvement of rehabilitation specialists and occupational and physical therapists who help patients use the device. It takes a very large interdisciplinary team to bring it all together.”

The device—dubbed the Argus II—was approved for use in the European Union in 2011, and Humayun notes that as many as 12 patients have subsequently started using it. Recently, an FDA panel voted unanimously in favor of using the Argus II in the United States. “It is no longer a research device,” Humayun says. “For the first time, if you are blind from certain conditions, you will very soon be able to go into the doctor’s office and get a retinal implant.”

Humayun believes that this approach—tapping directly into the brain using the body’s electrical systems—represents an exciting new area in medical research.

“Your whole body runs on tiny electrical pulses,” he says. “And medicine now only treats you with drugs or surgery, with very few devices that interact with the body’s electrical grid. This idea of understanding and speaking the bioelectric language of the body is a rapidly expanding new area. You have to learn and understand how bioelectrical networks work in the body. There’s electrical input to your gut, your pancreas, your eye, your brain. So this is just the tip of the iceberg. I envision that as we develop these devices we’ll learn a lot more about this bioelectrical language of the body.”

Neuromodulation

The founders of NeuroSigma, a Los Angeles–based medical-device company, often refer to the human trigeminal nerve as “the USB port to the brain.” Using that nerve as a point of access, the company is currently developing a number of therapies that researchers believe will change treatment strategies for neurological and psychiatric disorders ranging from drug-resistant epilepsy to depression to post-traumatic stress disorder (PTSD).

The trigeminal nerve is a large cranial nerve that spreads under the surface of the entire face, with branches emerging just below the brow and running back from the skull, all the way to several key areas of the brain. These areas are the regions where mood, emotion, attention, concentration and sleep are regulated, explains Dr. Ian Cook, one of the senior medical advisers at
NeuroSigma and a professor at the University of California, Los Angeles School of Medicine's Department of Psychiatry. By stimulating the nerve with precisely calibrated electrical pulses, it is possible to affect the metabolic activity of cells in the cerebral cortex—a process called “neuromodulation.” And research has shown that this stimulation can reduce symptoms of depression or decrease the frequency of epileptic seizures in some patients.

Because the trigeminal nerve runs very close to the surface of the skin, the NeuroSigma system—known as the Monarch—is noninvasive. The patient simply applies a 3.5-inch-by-1-inch patch to the forehead, and the electrical pulses are sent through the skin to branches of the nerve that run from the eyebrows up to the top of the head.

“A wire lead connects the patch to a pulse generator, which is a small device just a little larger than a cellphone,” explains Cook. “For depression, our recommendation is that people use the device about eight hours a night while they’re asleep. For epilepsy, the recommendation is to start with eight to 12 hours, with potential to use it up to 16 hours. The sensation that people get when they use it is that there’s a buzzing feeling or a tingling or tickling in the forehead when the device is active. People tend to not notice it after a few minutes of it being on.”

The Monarch has received certification for the treatment of epilepsy and major depressive disorder in the European Union, and the researchers at NeuroSigma believe there is a wide range of neurological and psychiatric disorders that will respond to neuromodulation through the trigeminal nerve.

Dr. Colin Kealey, a physician and manager of business development for the company, is particularly excited about the use of neuromodulation as an emerging alternative to multiple-drug therapies. Drugs, he notes, represent a systemic approach to treatment, while external neuromodulation can be very precisely targeted to specific regions in the brain. He also notes that, for many patients, physicians might have reached the limit of what a
pharmaceutical approach can achieve.

"We’re just at the beginning of where neuromodulation and neurostimulation are going to go," Kealey says. "At the same time, there have been 15 new drugs for epilepsy in the last 20 years. Yet the number of patients who are drug resistant—which is about a third of the total population—remains essentially unchanged. We believe that trigeminal nerve stimulation—TNS—is at the forefront of a wave of coming neuromodulation technologies. So this is just the beginning."

**Telemedicine**

The Internet and modern communication technology have eliminated long-held notions about time and space in many areas of our lives. And communications technology is bringing profound changes to the medical profession, as well.

Already, physicians are routinely transmitting X-rays and lab tests around the world for overnight analysis. So it should not be surprising to find that many aspects of patient monitoring are now being managed in centralized facilities many miles away from the hospitals where the patients have been admitted.

St. Louis–based Advanced ICU Care is a pioneer in providing remote monitoring services to intensive care units (ICUs) around the country. Dr. Mary Jo Gorman, the company’s CEO, says that the company started offering its telemedical services in 2006, as a response to a growing shortage of intensivists—medical professionals qualified to work in the nation’s intensive care units. With support centers in St. Louis, New York and Chennai, India, Advanced ICU Care currently works with more than 24 U.S. hospitals, with clients across the country from Philadelphia to Merced, California.

While the hospitals maintain their own on-site staffs, Advanced ICU Care typically backs them up with a crew of physicians and nurses. Cameras and a suite of sensors provide a real-time stream of data on patients’ conditions. Communication links allow the company’s specialists to communicate directly with the on-site staff as the need arises.
Explaining how the system works, Gorman describes a recent example of how a remotely stationed nurse likely saved the life of an ICU patient.

“One of our nurses was monitoring her patients, and she saw that one patient was having a rapid escalation in his blood pressure and pulse rate,” Gorman says. “She knew that the patient was on a respirator and that he was being sedated, and was paralyzed. It didn’t make sense that a patient who was sedated should have this rapid run-up in his pulse and blood pressure. So she announced that she was coming into the room—virtually—and with the camera she began to examine each of the IV bags in the room.”

With the aid of the camera, the nurse was able to determine that the IV bag containing the patient’s sedating medicine had run dry. The patient was now becoming aware of being both paralyzed and hooked up to the respirator—this explained the escalation of his pulse rate and blood pressure. The nurse at the support center called the nurse on the patient’s hospital floor, who immediately came to the room and replaced the sedation bag.

“This possibly prevented a serious stroke or other problem,” Gorman says. Gorman cites company studies that show that the telemedicine service has reduced mortality by 40 percent and length of stay in the ICU by 25 percent in client hospitals.

In addition to saving lives and improving treatment, this kind of service can also be financially meaningful to hospitals, Gorman says. “I think that telemedicine is going to save the system at all levels. There are fundamentally not going to be enough caregivers at any level to take care of our aging population,” she says. “The future of solving that problem has to be based on technology.”

**Containing Costs: Improving Outcomes**

Mark Valentine is the president of The Heart Hospital Baylor Plano, in Plano, Texas. More than most, he understands the imperative of delivering quality health
health insurance. a.k.a. “that thing you know you should have but can’t afford.”

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care while controlling the costs that threaten to overwhelm the system. Valentine is a strong advocate for bringing new technologies into play, and demonstrating how even expensive new procedures can ultimately reduce costs by improving patient outcomes over the long run.

He cites the example of a new procedure being used by cardiologists at Baylor Plano. Transcatheter Aortic Valve Replacement is a minimally invasive operation that allows surgeons to replace defective heart valves using nothing more than a catheter that is inserted in the patient’s leg. Guided by remote control, the catheter is threaded through an artery, delivering the replacement valve to the desired location while the patient is under general anesthesia. In the past, Valentine notes, the treatment required open-heart surgery, a four- to six-hour operation that involves cutting through the chest bone and actually stopping the heart while the valve is removed and replaced.

“TISS new procedure takes about 90 minutes, and patients have an average length of stay of about four days,” Valentine says. “In a traditional aortic valve replacement, patients usually stay in the hospital from six to 10 days. It’s very painful, and it’s high-risk surgery.”

Valentine admits that the new, high-tech procedure is initially expensive. But he believes the high cost is offset by factors such as a shorter length of stay, fewer days in rehab, a reduced drug regimen and a low readmission rate.

“You have to look at the whole episode of care,” he says. “People fixate on the immediate cost, and, yes, there is a premium to that technology. But when you look at the whole episode of care, it’s cost-effective.”

The high cost of health care is on everyone’s mind these days, and technology alone won’t solve all the problems. But as long-term outcomes are weighed against short-term costs, technology is increasingly a key piece of the solution. With 21st century technology, the future is here today; the benefits physicians are seeing now may resonate for generations to come.

Dayton Fandray lives in Arizona.