When 86-year-old Kathryn Thompson flew home to Englewood, FL, after a three-week vacation in Spain, she felt a bit under the weather. A cold, she thought, or maybe bronchitis, her primary care physician surmised.

Little did this globetrotting great-grandmother know that she was about to experience first-hand what Microsoft Chairman Bill Gates predicts could be the next hot health technology: medical robotics.

Thompson became one of the first patients to undergo robotically assisted surgery at the Venice Ocala Heart Institute in Florida for what turned out to be a small—but growing—malignant lesion on her lung.

“At my age, I figured, ‘What have I got to lose?’” says Thompson, whose travels have taken her around the world and hiking up the Inca Trail in Peru. “The amazing part was the recovery time. Compared to other surgeries I’ve
had, I was out of the hospital so quickly and ambulatory—with little or no recovery time. I just couldn’t believe that I healed so quickly. It was very successful.”

In just over a week, she was out of the hospital—and feeling little need for the assistance her family offered. Within two weeks, she had resumed her normal activities, including driving a car and walking to the grocery store. Reached a few months after surgery, she reported that she was “very comfortable.” In fact, she was preparing for a long-distance road trip to visit a nephew.

Minimally Invasive Surgery
Typically, a patient with Thompson’s diagnosis would require a thoracotomy, an incision between the ribs that may require spreading the ribs apart. That surgery can be “rather painful and debilitating,” Thompson reports that her surgeon told her. Postoperative complications, including the risk of pneumonia and infection, can make for a long recovery.

Thompson was a fortunate beneficiary of Venice Ocala Heart Institute’s implementation of Intuitive Surgical’s da Vinci® Surgical System earlier this year. This state-of-the-art robotic technology system enables surgeons to perform delicate and complex operations with just a few tiny incisions, or “ports,” rather than one or more large incisions. This system for minimally invasive surgery supports a number of specialties, including cardiothoracic, colorectal, general, gynecological, head and neck, and urologic surgery.

The first and as yet only U.S. Food and Drug Administration (FDA)-approved, all-encompassing, robotically assisted surgery system includes surgical instruments, camera and scopic devices that can be used for many types of procedures. It consists of:

- An ergonomically designed surgeon console, which provides a high-definition, 3D image with up to 10x magnification inside the patient’s body. The surgeon sits at the console and operates master controls, using proprietary EndoWrist® instruments that translate the surgeon’s hand, wrist and finger movements into precise, real-time movements of surgical instruments working inside the patient’s body.
- A patient-side cart, which is where the patient is positioned during surgery. From the console, the surgeon operates three or four interactive robotic arms on the patient-side cart that carry out the surgeon's commands. The robotic arms move around fixed pivot points, which reduces trauma to the patient, improves the cosmetic outcome and increases overall precision. Every maneuver is under the direct control of the surgeon, with repeated safety checks that prevent independent movement of the instruments or robotic arms.

Magnifying the Effects of Surgeons
Mateo Dayo, the cardiovascular thoracic surgeon at the Venice Ocala Heart Institute who performed the robotically assisted surgery on Thompson, has become a big fan since he started using the da Vinci Surgical System in February 2011. In fact, for many of the 200 operations he performs each year, Dayo now considers robotically assisted surgery as a first option.

“It’s so much easier and safer than traditional open surgery or even laparoscopic surgery,” Dayo says. “I have more precision, control and dexterity than with a long-shafted instrument. The robotic instrument moves like your wrist. The 3D, binocular display makes it feel like I’m sticking my head in the patient’s chest. The visualization is so good that I swear I can feel inside the patient.”

He’s describing haptics, a tactile feedback technology that takes advantage of a person’s sense of touch by applying forces, vibrations, or other motions that deliver a palpable signal—like a cell phone in vibration mode. But the da Vinci Surgical System doesn’t use haptics—yet. “It’s like the visualization helps you overcome the lack of a sense, like a blind person who develops an acute sense of hearing to compensate for lack of sight,” Dayo says. “The mind does trick you.”

At Venice Ocala Heart Institute, the surgeon console sits inside the operating room—close enough that the surgeon could jump up and be at the patient’s side in a matter of seconds if the surgery went awry. Once, in fact, a robotically assisted surgery did result in an emergency blood loss in a patient that required him to do

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Kathryn Thompson
just that. It wasn’t the robotic medical equipment that failed, he is quick to add, but a surgical stapler. So, while the surgeon console could be located more remotely from the operating room, Dayo says he doesn’t envision performing complicated lung surgery “from another zip code.”

Dayo doesn’t believe that robotic medical technology will replace surgeons. Instead, robots will work side by side with surgeons, like driver’s education instructors sit beside and assist people who are learning to drive. A human surgeon’s irreplaceable ace-in-the-hole is professional judgment, honed by the experience of performing thousands of surgeries with all sorts of complicating factors over the course of years, he says. Surgeons still plan every surgery, make contingency plans, collaborate with others on the healthcare team and orchestrate every surgical move.

In fact, he says, “This technology could save some careers. Older surgeons shouldn’t fear this—it could extend their careers. The older you get, you lose depth perception. The 3D binocular vision overcomes that.” Likewise, the technology compensates for loss of dexterity and fine motor control by correcting hand tremors, scaling, filtering, and translating motions precisely. The instruments also provide a greater range of motion than the human hand. “Surgeons stand all day,” he adds. “Back and feet pain ends many careers. You’re sitting down in the console.”

Jacob Rosen, associate professor of computer engineering and director of the Bionics Lab at the University of California, Santa Cruz, concurs. “Sixty to 70 percent of a surgeon’s skill is decision making, 30 percent is manual dexterity,” says Rosen, co-editor of Surgical Robotics: Systems, Applications, and Visions, a book published in 2010. “I’m working with a neurosurgeon who is approaching 60. He’s in the prime of his life. Surgeons who are getting older are at the highest level of decision making, but they might suffer degradation in manual operations.” Robotic-assisted surgical implements could keep their hands working with the same steady proficiency as their brains.

Another surgical system that improves upon “freehand” surgeries comes from an Israeli company, Mazor Robotics. The company introduced its Renaissance™ spinal robotic...
surgical guidance system in July 2011, an update on its SpineAssist® system. The system increases surgeons’ accuracy and efficiency in delicate spinal surgery and implants. The new platform will support robotic-guided cranial surgeries in the future.

The Biomed’s Role
To learn to use the da Vinci Surgical Suite, surgeons train with Intuitive Surgical, which provides a comprehensive training program with knowledgeable faculty and hands-on practice.

Hands-on practice is equally valuable for clinical and biomedical engineers and technicians, according to Anthony Crowley, biomedical engineering technician at Duke University Hospital. “We use our da Vinci when it is not in service,” Crowley says. “We do the same things a surgeon would do in training. We sit in the console, play with the controls, see how the two-camera system works. It makes it easier for us to see what the surgeon sees and helps us to troubleshoot with the surgeon if there are any problems.”

Duke University Hospital has a service contract with Intuitive Surgical for services such as preventive maintenance and automated software updates. But there are times when biomedical technology professionals’ assistance is needed to keep the system up and running, Crowley says. Camera or other equipment issues can occur.

“We had a glitch with a camera,” Venice Ocala Heart Institute’s Dayo says. “We called our service support. It was really helpful to have a human being at the end of the line. We put him on speakerphone and he helped us fix the problem.” The ability of biomedical technology professionals to understand clinicians’ experiences with medical robotics and translate them into language that technical service providers understand is invaluable, he adds.

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that seals medical equipment in a humid environment that prevents it from drying, thus making cleaning easier.

**Advancing a Career**

The career outlook for biomedical technology professionals with robotics training is rosy. People with robotics skills are in demand and well compensated, according to Howie Choset, professor of robotics at Carnegie Mellon's Robotics Institute.

This emerging multidisciplinary field is one that Carnegie Mellon and the healthcare community in Pittsburgh, profiled on page 358, are supporting by developing curricula to teach engineers about surgery, among other education initiatives. Other higher education institutions are beginning to offer robotics programs as well.

**The Past and Future**

Robotic devices are well established in advanced manufacturing, but only now coming on strong in healthcare. “My personal opinion is that, when the economy tanked back in 2007–08, old-line robotics manufacturers began to look at the medical area as a way to diversify,” says Charles Sidebottom, director of corporate standards at Medtronic and immediate past chair of the AAMI Board of Directors.

A standard manufacturing procedure, in fact, was the genesis for an idea that proved the concept for robotically assisted surgery 20 years ago, Rosen says. “Orthopedic surgeons essentially used a hammer and a chisel to prepare the long bone for total hip joint replacement,” he says. “The idea was to use a robot to perfectly scan and mill the bone so there would be a perfect match between the bone and the implant—the same concept as in an assembly line that manipulates machine parts. From an engineering perspective, it was a success. But the FDA approval process was complicated since the life span of the implant is 15 years.”

Another early approach to medical robotics was artificial intelligence, with attempts to program robotic devices to make intelligent decisions on their own. That research “was slow to deliver, but it is still an active academic effort that is now attempting to add artificial intelligence and independent decision making to the surgical robotic system itself.” Rosen says.

He attributes the reinvigoration of the field to a focus on the human–machine interface. “There’s a need to bring people back into the loop,” he says. The two fundamental fields of medical robotics do exactly that, according to Rosen:

1. **Surgical robotics**, exemplified by the da Vinci Surgical System, which use a “master and slave” architecture. The surgeon is the “master” who controls the system, the “slave” is the part of the system that interfaces with the patient and follows the surgeon’s commands. In the future, robots likely will be more intelligent—not just doing what surgeons tell them to do, but alerting them if they are about to make a mistake, and taking on rote actions and automating repetitive motions. “People are very good at decision-making, but very bad at repetitive motion activities,” Rosen says. “Suturing can be automated.”

A few years ago, the Defense Advanced Research Projects Agency (DARPA) funded a proof of concept demonstration that showed it is possible for robotics to support fully automated surgery from a remote location. One day, such telesurgery could be used routinely to provide healthcare in trauma zones or in the aftermath of natural disasters that wipe out or take down medical capabilities.

On a related note, medical students, physicians and other clinicians at some healthcare facilities, such as Tulane University School of Medicine’s Center for Advanced Medical Simulation and Team Training, learn and practice surgical and other medical skills on robotic “patients.” These robots, which are built to look like real people, can be programmed with specific symptoms and respond to clinicians’ actions with verbal expressions and physical movements. Robotic-assisted education, training and simulations are expected to be another growth area for medical robotic applications.

2. **Rehabilitative robotics**, which can use the “master and slave” architecture as well. Rehabilitative robotics are also known as “human interlopers,” which means they effectively share
the same space as people and serve both patients and healthcare providers, including physical or occupational therapists. The two main categories of rehabilitative robotics are prosthetics, which replace a missing limb, and orthotics, which sit on top of an existing, nonfunctional limb. Rehabilitative robotics assist people by enhancing mobility.

For example, prosthetic iWalk PowerFoot BiOm, introduced in 2011, is the first bionic lower leg system. It replicates the movements of an amputee's foot, ankle, and calf muscles, using microprocessors, sensors, a motor, and a carbon-fiber spring, making for a more natural and powerful gait than traditional prosthetics. Robotic prosthetics also can connect human nerve endings with tiny electronic sensors, which allow people to “feel” things when they are used.

This human–machine interface is the frontier of wearable robotics (orthotics and prosthetics), Rosen says. “The mechanics are not the problem,” he says. “Wearable robotic systems are using both internal and external electrodes as a source for neural input commands.” Eventually, these electrodes could be implanted routinely inside the body. “Biocompatibility is the issue. The body recognizes this as a foreign body. That’s the limiting factor in this entire field. Creating a reliable interface at the neural level is an unsolved problem.”

Research funded by DARPA at Johns Hopkins University’s Applied Physics Laboratory, with collaborators at Caltech and the Universities of Pittsburgh, Utah and Chicago, is tackling that problem with a project to develop a mechanical arm powered by brain-controlled signals.

In orthotics, meanwhile, the hot robotic medical technology is the exoskeleton, a lightweight, motorized device worn on top of clothing that moves with a person. This device helps partially disabled or elderly people walk, balance themselves and support their weight. The U.S. Army is testing exoskeletons that will help soldiers carry loads of up to 200 pounds, with minimal physical exertion.

In healthcare, exoskeletons could help people prolong their therapy and recover from strokes or other debilitating conditions faster. “From the motor-control perspective, a stroke takes a grownup and brings him or her down to the level of a baby in their ability to control their limbs,” Rosen says. Rehabilitative therapy is costly—and insurance payments for therapy may not last long enough for many stroke victims to make a full recovery. Using an exoskeleton, they’re not limited to three times a week with a physical therapist—they can keep moving with this assistive device. “Technology is changing the entire game,” Rosen says. “The therapist can supervise treatment. They don’t have to be in one-to-one sessions with a patient. They can supervise 10 people in a room. It’s a force multiplier, as they call it in the military.”

A cross between the rehabilitative and orthotic applications is the robotic treadmill, a combination of an automated treadmill and exoskeletal supports that help patients relearn how to walk, a therapy known as gait rehabilitation.
Pittsburgh: A Hotbed for Robotics Technology

When President Obama announced the launch of a new National Robotics Initiative in June 2011, his venue fit the occasion: Pittsburgh. The city is home to Carnegie Mellon’s Robotics Institute, a global leader in researching and developing robotics technology, including medical robotics.

“Medical robotics at Carnegie Mellon epitomizes the Carnegie Mellon and Robotics Institute philosophy of doing multidisciplinary basic research in the context of a real problem,” says Howie Choset, professor of robotics at the Robotics Institute. “So in medical robotics, we are trying to develop theory and discover new truths, but you have to have that application in mind. We’re very aggressive about getting into the operating room and trying our devices on live animals whenever possible.”

The Three Rivers city has a confluence of other infrastructural advantages that make it a hotbed for medical robotics:

- World-class medicine at UPMC, a $9 billion, 20-hospital global health enterprise affiliated with the University of Pittsburgh Schools of Health Sciences with more than 50,000 employees headquartered in Pittsburgh, and at Allegheny General Hospital, which is run by Temple University
- Visionary leadership from the Pittsburgh Life Science Greenhouse, an organization that provides capital investments and business development services to help life science researchers and developers move their entrepreneurial innovations to the marketplace, and the Technology Collaborative, an economic development organization that focuses on growing robotic and other advanced technology companies
- Strong biomedical engineering programs at Carnegie Mellon and the University of Pittsburgh and, at Carnegie Mellon, internationally renowned robotics education programs that span the K–12, undergraduate and postgraduate levels

In this environment, Choset and his team, including surgeon Marco Zenati and mechanical engineering researcher Alon Wolf, tackled the problem of cardiac disease by developing a surgical snake robot for minimally invasive cardiac surgery.

“The idea is, either you have a rigid laparoscope that can enter through a small incision but only reach a limited volume, or you have a flexible endoscope that buckles very easily,” Choset says. “A small surgical snake robot inherits the benefits of both. It’s both flexible and rigid so you can access small targets without making big incisions.”

The surgical snake robot proved successful in clinical trials. Now, a company founded by Choset and Zenati with support from the Pittsburgh Life Science Greenhouse, Medrobotics, is shepherding the surgical snake robot through the FDA approval process.

Choset continues his research in applying robotics to real medical problems. He is now collaborating with Shyam Thakker, a surgeon at Allegheny General Hospital, and Michael Awad, assistant professor of surgery at Washington University School of Medicine in St. Louis, to develop a robotic endoscope for natural orifice transluminal endoscopic surgery (NOTES).

With NOTES, Choset explains, you enter through an orifice instead of cutting through the flesh. “You poke a hole in the luminal tract and you drive to the organ where you want to deliver your therapy or perform your diagnostic. Your luminal tract heals faster than your flesh.” NOTES surgery would reduce post-op discomfort and reduce healthcare costs.

“What we want to do to disseminate medical care is develop tools that people with less training can do,” Choset says. “We’re already seeing that. Forty years ago, if you had something wrong with your intestines, they’d cut you open, look at the inflammation and give you prednisone. Now we have colonoscopies. You don’t need a surgeon to do a colonoscopy. In fact, a medical student can do a colonoscopy.”

Minimally invasive robotic devices open up the possibility of delivering sophisticated healthcare in less sophisticated environments, such as rural areas and developing countries where patients don’t have access to medical specialists or advanced healthcare facilities.

Other robotic medical devices in development at Carnegie Mellon that Choset is excited about include:

- An orthopedic surgical robot that can shave the femur precisely to receive a knee implant
- The Sonic Flashlight™, a hand-held, low-cost device that uses ultrasound to produce a “poor man’s X-ray” as a quick diagnostic tool that could be used by emergency medical responders

The National Robotics Initiative is part of the Advanced Manufacturing Partnership (AMP), a $500 million national effort bringing together industry, universities, and the federal government to invest in the emerging technologies that will create high-quality manufacturing jobs and enhance global competitiveness. Like the Obama administration, Choset believes medical and other robotics technology will produce U.S. manufacturing jobs.

“This may be the last time, in our lifetimes at least, that we have a fighting chance to reclaim our manufacturing base through innovation,” he says. “And a lot of the innovation will be in robotics.”

The National Robotics Initiative will plow $70 million into research on next-generation robotics, with funding from the National Institutes of Health, the National Aeronautics and Space Administration, the National Science Foundation, and the U.S. Department of Agriculture. Carnegie Mellon will work in partnership with the Massachusetts Institute of Technology, Georgia Institute of Technology, Stanford University, University of California-Berkeley and University of Michigan.
In the United States, iRobot Corp., best known for its consumer, government and military robots, and inTouch Health, a leading remote telemedicine solutions provider, announced in July 2011 that they were teaming up to develop robotic solutions for the healthcare market.

Toyota Motor Corporation, meanwhile, implemented robots into factory automation more than three decades ago. In the past decade, the company launched a major “Partner Robot” initiative. Toyota has used its robotic manufacturing prowess to develop fanciful robots that bear a striking resemblance to C-3PO from Star Wars. These “Humanoid” robots play violins, trumpets, and other musical instruments—and are a YouTube sensation.

This proof of concept has led to more serious prototypes in healthcare from Toyota, including “Robina,” a robot that can provide medical or nursing care and assist doctors and nurses. “Winglet,” a personal transport assistance robot that is driven in a standing position, and “Mobiro,” a personal mobility robot that is driven in a seated position.

In the United States, iRobot Corp., best known for its consumer, government, and military robots, and inTouch Health, a leading remote telemedicine solutions provider, announced in July 2011 that they were teaming up to develop robotic solutions for the healthcare market. iRobot consumer products include the Roomba® floor vacuuming robot, Scooba® floor washing robot, Verro® pool cleaning robot, and Looj® gutter cleaning robot. iRobot government and military robots are deployed on land and sea operations, such as search, reconnaissance, and bomb-disposal missions. InTouch Health is best known for Remote Presence, a technology solution that allows for remote physician–patient consults.

Medical Robots in Japan

Robots bound for hospitals are getting smarter in Japan.

That, anyway, is the assessment of the Center for Symbiotic Human Robotics Research at Toyohashi University of Technology in Honshu, Japan, which says it is taking a new approach to the design of robots for healthcare environments.

“Instead of spending our funds on building complicated robots of limited use, we’re developing much simpler, power-assisted systems that can help the infirm move about comfortably and safely,” says Kazuhiko Terashima, head of the center.

In a press release, the center says that in its design of robots, they are “considered part of an overall system of care, controlled directly by humans such as nurses and aides” who will be needed to reassure patients.

So what could these robots do? Help to lift and move a bed-ridden patient. “Wheelchair robots,” says the center, are also in the works to help transport patients.