

The Future Is Now

by Élan Young

“As for the future, your task is not to foresee it, but to enable it.”

– Antoine de Saint-Exupéry

Never mind the much-hyped remake of the television series *Bionic Woman*. In 2006, Claudia Mitchell became the real thing. Although Hollywood and human fantasies endow bionics with superhuman strength, Mitchell, a 27-year-old student and former Marine, is happy to

use her new prosthesis to get back to living a normal life. Although its range of motion is still limited in comparison to the real thing, all she has to do is think about moving it, and it does. Continuous advancements in prosthetic and biomechanical technology are reaching beyond the realm of what once would have been dismissed as science fiction. This has given rise to speculation that one day upper-extremity amputees may be able to regain all the function and sensation in a bionic arm that a natural arm provides. According to the experts, this futuristic dream is not far from becoming a reality.

After becoming a functional shoulder disarticulation amputee in a motorcycle accident in 2004, Mitchell had resigned herself to living life with one arm. Even though she had been fitted with a myoelectric arm that was capable of performing many tasks, she couldn't communicate with it easily, despite her best efforts. Her turning point came when, after an hour of trying to get her arm to cooperate as she ironed a shirt, she had gotten nowhere. “I just wanted to grab my shirt collar and pull it to press it straight, but I couldn't do that because I couldn't tell my arm to close the hand and I couldn't tell my hand to extend the elbow,” she says. “I cried. I was so frustrated when I couldn't make it work that I thought, ‘Forget this; I can do this better without my arm and that's just what I'm going to have to do.’”

Jesse Sullivan and Claudia Mitchell demonstrate the capabilities of their RIC six-motor, neural-controlled prosthetic arms with a high five.

Photo courtesy of the Rehabilitation Institute of Chicago.



Claudia Mitchell, wearing the RIC six-motor arm, participates in functional testing at the RIC Neural Engineering Center for Artificial Limbs (NECAL) lab. *Photo courtesy of the Rehabilitation Institute of Chicago.*

Compared to an arm, the leg has relatively fewer joints that allow mobility. Lower-extremity amputees now have prostheses equipped with microprocessors that enable users to adjust their gait to match several different ground surfaces. The arm, by contrast, has a myriad of movements. In the forearm alone, 18 muscles control the hand and wrist. Even the best upper-extremity prostheses offer limited shoulder rotation and wrist flexion and extension, not to mention finger articulation. Muscles in the shoulder and chest are used to power a standard myoelectric prosthetic hand, but for many people this process seems awkward and confusing.

Through the summer and fall after her accident, Claudia learned how to live a normal life as best she could. Then, one day a

friend showed her a *Popular Mechanics* article highlighting the advancements made in upper-extremity prostheses at the Rehabilitation Institute of Chicago (RIC).

The clinical research at RIC under Todd Kuiken, MD, PhD, director of the Neural Engineering Center for Bionic Medicine, was breaking new ground as Jesse Sullivan, a bilateral shoulder disarticulation amputee, became living proof that an experimental nerve transfer procedure called Targeted Muscle Reinnervation (TMR) could lead to more control in motorized myoelectric prostheses. Sullivan, a power line technician who lost his limbs due to severe electrical shock, received the surgery in 2001 and was fitted with the first version of Dr. Kuiken's bionic arm in 2003. The 2004 article that caught Mitchell's

attention described how his cutting edge prosthesis could be controlled by the mind. That was a spark of hope to a woman who had no shortage of will, yet was unable to make her prosthesis work for her. "It was like the classic cartoon where the person's sitting there and the light bulb pops up over their head," she says. "I thought, 'If he's got one, I want one and we're going to make this happen.'"

With a little investigative research, Mitchell was able to find the right person at RIC to listen to her story and relay it to Dr. Kuiken. When he called her back, she was ecstatic. Within a couple of months, he invited her to Chicago for a consultation. "My mama was apprehensive," she recalls. "She said she would feel better if I talked to [Sullivan] since he'd already had the surgery."

When Mitchell met Sullivan and Dr. Kuiken's team at RIC, it dawned on her how close she was to changing her life. "Just a couple months before, I realized that I was not going to use the arm I was given — not at the fault of anyone. The technology just wasn't there," she says. "So there I was, thinking, 'Wow! This could really happen.'" The team thoroughly discussed the procedure with Claudia, letting her know what was realistic as well as what could go wrong. "I understood that it was a research project," she says. "I was taking a chance, but I felt it was worth it."

TMR, a technique developed by Kuiken, who has been working on this research for over 20 years, transfers arm and hand nerves into chest muscle. When the nerves grow into the muscle, the result is that the chest muscles then "think" like hand muscles. When a prosthesis user thinks about contracting his or her hand, the contractions are measured by myoelectric signals that cause the prosthetic hand to respond. In other words, it is physiologically correct. TMR lifts the extra mental load required by amputees, like Mitchell, who struggle to power a prosthesis with shoulder, chest and back muscles.

When Sullivan received the TMR surgery, it was to reduce sensitivity from the skin grafts at his amputation sites that were causing him pain, and also to give him more control of a prosthesis. In a striking discovery, researchers found that the reinnervation procedure allowed him to regain sensation in his transferred nerves. When patients are touched on the patch of skin covering the transferred nerves, they feel as if their hand is being touched. This alone holds great promise for the future. "It's an exciting area of science to see if we can give amputees a feeling from their prosthesis as if it were their own hand," says Kuiken.



Occupational therapist Kathy Stubblefield, OTR/L, works with Claudia Mitchell in the NECAL lab. Photo courtesy of the Rehabilitation Institute of Chicago.

For Dr. Kuiken and the team at RIC, 2005 was a big year. The bionic arm project was publicly unveiled as Sullivan began using a six-motor version of the arm that provided even more dexterity. It was also the year that Claudia became the first female to receive the TMR surgery. Three months after the surgery, she could feel the reinnervation taking effect. When she thought about squeezing her nonexistent hand, she could tell that her chest muscles were working. When the patch of skin on the left side of her chest was touched, it felt as if her hand were being touched. Six months after the procedure, she was fitted with a prosthesis and began physical therapy.

Mitchell continues to participate enthusiastically in testing the latest robotic arms in development at RIC. Direct feedback from patients with TMR helps the researchers understand what will and won't work with bionic arms and advance the technology even further. When RIC publicly presented her as the first bionic woman in 2006, she received a flurry of media attention, but for her, the focus has always been on the research. "Whether it's an engineer or a senator, the more people realize what we are doing and the need that exists, the better," she says. People ask her why she is still involved in the research. "The thing is," she explains, "I am in the ear of the people who are designing these arms. I want amputees to have the best chance for arms that feel more natural, work better, and have finger dexterity. I want them to have it all."

The Defense Advanced Research Projects Agency (DARPA) also wants amputees to have all this, especially those who have lost limbs while serving in the military. In 2006, it launched the Revolutionizing Prosthetics 2007 and 2009 initiatives. DARPA gave a combined \$50 million in grant funding to the Johns Hopkins University Applied Physics Laboratory (JHU/APL) and DEKA Research and Development Corp. to bring the "complexities of biology into the world of engineering." Researchers and clinicians

at a handful of other institutions, including RIC, work under subcontract with JHU/APL and DEKA to meet DARPA's challenge: create a mechanical arm that has the properties of a biological limb. Currently, the focus is on upper extremities, but these developments may also help lower-extremity amputees in the future. The result of such a huge injection of dollars into the research means that advancing ideas and technology are moving ahead rapidly.

Back at RIC, in the Biomechanics Development Laboratory, the research scientist who worked with Otto Bock – Vienna and JHU/APL to create the mechanical design of the first prototype bionic arm, also directs a separate research project. (Proto 1, the first prototype bionic arm, was completed within the first year of the project and was fitted to Sullivan.) For the past four years, Richard F. ff. Weir, PhD, has been working on Injectable MyoElectric Sensor (IMES) devices in an effort to improve the signals coming from the residual muscles and, therefore, control a more complicated prosthesis. The IMES are about 2mm by 12mm encapsulated cylinders that, when injected into the muscle of the residual limb, would send signals wirelessly across the skin barrier to control a prosthesis. They have already been demonstrated to work in animals; while Weir waits for approval from the Food and Drug Administration (FDA) to begin human testing, the feeling at RIC is that IMES will complement TMR and drastically improve their chances of meeting DARPA's challenge.

For now, TMR holds the greatest promise of providing greater degrees of freedom for high-level, upper-extremity prosthesis users. It is out of its research phase and has a strong enough record that it is now available to the general public. Over a dozen patients have received the surgery so far, and all but one was successful. Ideal candidates have had an above-elbow or shoulder disarticulation amputation within the past three years and must have the ability to wear an arm. "We can make the

control better, but the myoelectric arms are still heavy and uncomfortable for some users,” says Kuiken. The technique can be performed anywhere there is a surgeon willing to learn it. Along with Gregory Dumanian, MD, the plastic surgeon at Northwestern University who performs Dr. Kuiken’s surgery, Douglas G. Smith, MD, an orthopedic surgeon at the University of Washington and medical director of the Amputee Coalition of America (ACA), has also performed the surgery. Kuiken wants to assure amputees that they

can work with physicians and prosthetists where they live. “We want the science to be spread to benefit the most people and take hold,” he says.

These exciting developments have thrown the door open to what else is possible. Proto 2, the second prototype from JHU/APL (also with heavy involvement from RIC’s Biomechatronic Development Laboratory) was presented to DARPA on August

5, and the DEKA Gen I arm is well under way. Both will provide the range of motion of a natural arm. The push for a final limb system, an arm that has sensation and fine-motor capacity, is an ambitious endeavor to give upper-extremity amputees something they’ve never had before. Typing, playing piano and playing baseball are only a few of the activities they may be able to experience with the next generation of bionic arms. In the meantime,

Claudia Mitchell is enjoying life in ways she never imagined in the early days after her amputation. She’s a marathon runner, an ACA-certified peer visitor, and a champion of the prosthetic future. ■

