

Upper-Limb Prosthetics: Part 2

Insights from those who have lost one arm



by Douglas G. Smith, MD

“Life is only this place, this time, and these people right here and now.”

– Vincent Collins, artist

If an upper-limb prosthesis could truly replace the human hand and arm, the job of healthcare professionals would be easy. We would give people exactly what they lost. Unfortunately, prostheses can perform only a fraction of the countless functional motions our arms and hands do automatically.

Because we cannot replace everything, we try to give people with single (unilateral) upper-limb loss the devices that will help them do the things they simply can't do with just one hand. One-handed tasks are very difficult. But with training, practice and simple tools, many people can learn to do amazing things with a single hand. A prosthesis becomes an enormous help for tasks that are difficult with one hand, and a necessity for tasks that simply cannot be done one-handed.

People who've lost both upper limbs (bilateral) are almost totally dependent on prosthetic technology, help from others, or both. Without prostheses, bilateral upper-limb amputees cannot eat, button a shirt, type, perform personal hygiene or any of the things that can be done one-handed. Matching upper-limb prosthetics with each unique individual is extremely important for people with either unilateral or bilateral limb loss. It's not an easy task, and people's needs can change, both over time and even in the course of a single day.

There are many upper-limb prosthetic devices to choose from, and their form and functions vary as much as the needs of the people who use them. Some prostheses

look very realistic. Some are very high-tech, even robotic in appearance. Some prostheses don't move at all; others can be set in specific positions. Still others are mechanical, powered by muscles, cables and springs. There are prosthetic devices that are activated by electrical signals run with batteries and motors. There also is increasing use of prosthetics that are combinations of anatomic-appearing, mechanical and electrical devices. Unlike the old days, when prosthetics were easily classified as passive, mechanical or electric, it's hard to force today's upper-limb prostheses into a single category. Sometimes, it's even impossible.

The Brain, the Body and Motion

One way to contrast the differences between the arms and hands that God gave us with upper-limb prosthetics is to compare the limited number of ways a prosthesis can be moved to the almost infinite number of ways we can move our natural hands and arms. The movements of our joints can happen simultaneously, smoothly, with brain and body working together in perfect unison.

When you pick up a cup, you don't consciously think about the way your shoulder and elbow extend, your arm rotates, your hand opens, your fingers close around the cup, your elbow bends and your hand brings the drink to your mouth. You just reach for it, drink, and put it down. Your brain tells the parts of your arm, from the shoulder down to your fingertips, to work in a continuous, fluid motion. It's so precise, yet so simple. We can even do it while doing something else, like reading a book or watching TV.

But a person with an above-elbow prosthesis must learn to rethink how each and every joint works to accomplish the same simple task. Each individual movement to

get the cup and take a drink must be consciously and painstakingly thought out:

- Shoulder – forward
- Elbow – bend
- Forearm – rotate the thumb up
- Hand – open around the cup
- Hand – close slowly
- Elbow – lift without spilling
- Head – move forward to the cup
- Sip – Finally!

Each prosthetic joint movement must be executed in a specific sequence. Then the person must go through another set of sequential motions to put the drink back down. And a person with an above-elbow amputation must watch the cup constantly because, without our natural elbow, we cannot accurately guide our hand to the cup and pick it up without maintaining visual contact with it. Compared to our natural ability, operating an upper-limb prosthesis can be time-consuming and awkward.

Profiles: People Who Have Lost One Arm

There's a world of difference between the various “makes and models” of upper-limb prosthetics because there are so many different kinds of people with unique needs. Recognizing the differences in people's prosthetic needs makes choosing and fitting the proper upper-limb device very important.

Devices count, but it's the people who use them who really matter. They say a picture is worth a thousand words. Hopefully, the following profiles of various upper-limb prosthesis users will illustrate their diverse prosthetic needs. And, as they say in the movies, any similarity between the characters, events or locations depicted here and actual people, events or locations is purely coincidental.

Bob: Below-Elbow Limb Loss.

Bob, 43, lives in a rural community. He lost his right arm below the elbow in a conveyor belt accident. He's undergone recovery and rehabilitation and returned to work. He also has been elected to his town council.

Bob still has his shoulder and elbow, which move smoothly through a wide range of motions to position and rotate his residual

forearm. For his factory job, Bob uses a traditional hard socket, mechanical cable prosthesis with a two-pronged hook. It works in a relatively simple way. A cable runs from the prosthesis up his residual arm and across his back to a harness on the opposite shoulder. When he rolls his shoulders forward, the distance between his shoulder blades widens and the cable stretches several inches, pulling

household tasks that he can't do one-handed or with his realistic, but passive, limb. The myoelectric device is quite complex. A sensor over the muscles on the front of Bob's residual forearm detects when his brain tells those muscles to fire (contract) like he was closing his hand. The sensor then sends a signal to the battery and motor to pull on a cable that makes the hand close. To release his grip,



Typical, below-elbow myoelectric prosthesis.

forearm. He can easily put the end of his prosthesis wherever he wants. His main prosthetic need is to open and close his artificial hand.

Bob finds it useful to have several prosthetic devices. He prefers to use an anatomic-appearing, passive hand at council meetings or in public. The hand-painted, silicon device looks very natural. He prefers to use it when he doesn't want to draw attention to the loss of his natural hand. But he doesn't wear it often, because he doesn't want it to get dirty. It's much easier to clean his natural hand. Isn't it amazing how easy it is to clean our natural skin, compared to things that are manufactured?

the hook open against its springs or rubber bands. When he relaxes his shoulders, the cable loosens and the springs or rubber bands snap the device closed. Bob can adjust the tension on the cable so that he can open and close the hook quickly or slowly. This kind of prosthesis is referred to as a standard body-powered, or mechanical, system for a below-elbow amputation level. The technology, developed during World Wars I and II, has survived because it's simple, functional and durable. It works.

At home, Bob doesn't want to use the device he uses at work, which gets dirty, so he switches to a myoelectric prosthesis for

household tasks that he can't do one-handed or with his realistic, but passive, limb. Bob's brain tells the muscles on the back of his residual forearm to fire, and the sensor reads the signal and sends it to the battery and motor to relax the cable and open the hand. It's great for almost everything – except washing dishes. “Can't get it wet!” Bob says. “Then you can dry them,” says his wife.

Ted: Above-Elbow Limb Loss.

Ted, 73, lost his arm above the elbow in the Korean War. Having lost the elbow, his prosthetic needs are more complex than Bob's. Ted has the use of his shoulder, but he needs to bend and extend his prosthetic elbow, rotate the forearm, and open and close the



Body-powered, mechanical below-elbow prosthesis.

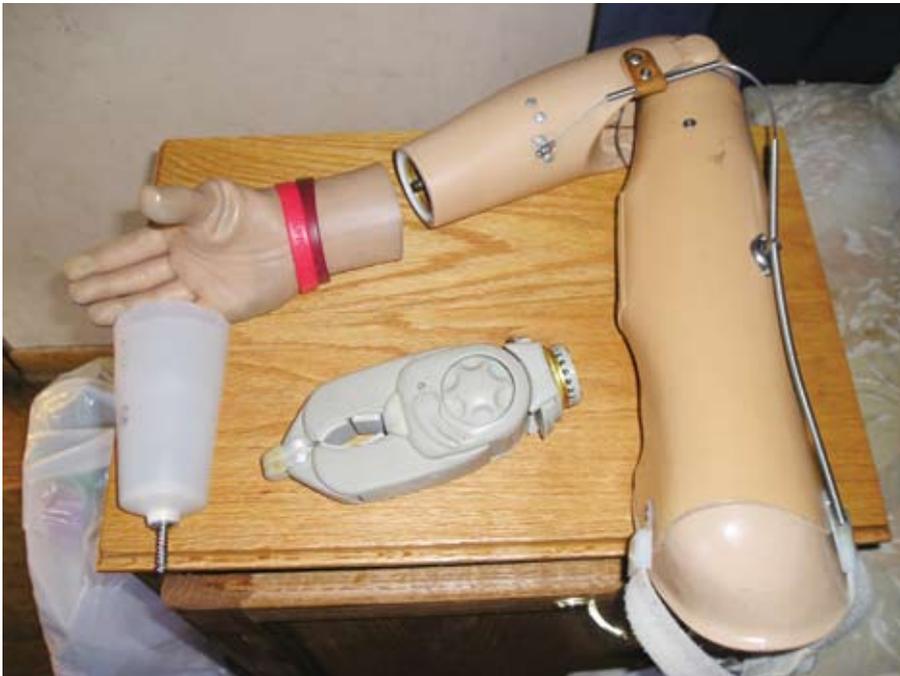
artificial hand. Like all above-elbow amputees, Ted has to mentally and physically manage three sequential tasks (elbow, rotation, hand) in contrast to Bob, whose prosthetic task is to simply open and close his hand.

Ted's first prosthesis was a body-powered mechanical device. He used a cable system similar to Bob's, harnessed to the opposite shoulder, to bend and extend his elbow. The elbow bent when he hunched his shoulders forward, pulling on the cable. Ted nudged a switch on the socket with his chin to lock the elbow into the position he wanted. After the cable locked, he nudged the switch again to get the cable to operate his artificial hand. The device was certainly useful, but because the elbow and hand were operated by the same cable, they couldn't work together at the same time. Ted had to nudge the switch repeatedly to change modes between the elbow and the hand. His prosthetic arm and hand motions were sequential and graceless, definitely not fluid and simultaneous. That always bothered him.

Because of advancing age and a bit of wear and tear, Ted now uses a hybrid device that uses both mechanical and electrical components. He uses the cable to bend the elbow and lets gravity extend it. He can lock the elbow. A myoelectric sensor takes signals from his residual biceps to close the hand and from the triceps to open it. Doing this does require some mental gymnastics. Ted thinks, "Biceps fire – hand closes; triceps fire – hand opens." A mechanical cable system operates the prosthetic elbow, and electrical signals from the sensor run the hand. This type of device takes a lot of patience, relearning and practice to learn to use, but Ted feels it gives him more functional options.

People with above-elbow amputations often look at prostheses differently from those with below-elbow amputations. Below-elbow amputees may find it more convenient to change devices because they are more concerned, prosthetically, with opening and closing the hand. But because people with above-elbow, shoulder-level or bilateral amputations have several prosthetic tasks, they tend to find a device that works best for them and stick with it. When the U.S. Department of Veterans Affairs offered Ted a realistic, passive device similar to Bob's, he declined. He simply doesn't feel he needs one. Ted, like many above-elbow amputees, typically goes for long periods without using a prosthesis. The device is heavy and can be cumbersome. He finds it refreshing to have his residual arm open to the air.

Ted has developed amazing one-handed skills, but he still needs his prosthesis for tasks he can't perform safely or comfortably with one hand. He doesn't wear a device 16 hours a day, like Bob and many other below-elbow amputees do. Some days he doesn't wear it at all. But Ted would be devastated without the prosthesis when he needs it. We often judge success with a below-elbow prosthesis by hours of use per day, and it's not uncommon for below-elbow amputees to wear a device all day, every day. But many above-elbow



Example of hybrid above-elbow prosthesis.

amputees may only use their prosthesis on certain days, for certain tasks, for just a few hours a day or even less.

Carol: Shoulder-Level Limb

Loss. Carol, 35, is a real estate agent who, because of cancer, needed a shoulder-level amputation. There's no residual arm at all to build a socket around. Carol's prosthesis is a combination mechanical and electrical device. Her socket wraps over part of her torso and is harnessed around the ribs on her unaffected side for suspension. Because of this, it's heavy and bulky. Her prosthetic shoulder is a hinge that can be locked in 35 positions. She uses her chin to hit a switch on the prosthetic shoulder that locks it into the position she wants, and repeats this action when she wants to unlock the shoulder and to lock it again.

Like Ted, Carol also needs a device to bend and extend the elbow, roll the forearm, and open and close the hand. But because she no longer has any biceps or triceps muscles, this is a very complex task. No prosthesis on the market even comes close to being able to move all the joints with

the same thought-free, fluid motions of a natural arm and shoulder. Carol, like all shoulder-level amputees, must activate the prosthetic joints one at a time, from closest to the amputation site to the most distant. She moves her residual shoulder forward, back and up to push toggle switches located at various touch points inside the socket to activate a battery and motor to operate the prosthetic joints. She hits a toggle switch in the front of the shoulder socket to bend the elbow and another in back of the socket to extend the elbow. She hits another switch to lock the elbow. Carol then touches the same forward toggle switch to rotate the arm with the hand facing down (pronation) or the back toggle switch to rotate the arm with the palm up (supination). She hits that switch to make the device change modes again, and uses the same forward toggle switch to close the anatomic-appearing hand and the back toggle switch to open it.

Having to go through pre-positioning and locking the shoulder, positioning and locking the elbow, positioning and locking the rotation and finally opening and closing the hand is very time-consuming and complex.

Small wonder that most shoulder-level amputees become frustrated and decide to use their prosthesis only when they have to.

Carol, like nearly all shoulder-level amputees, uses a prosthesis only occasionally. She's concerned about her core body shape and how clothing fits, particularly when she shows homes and properties to prospective buyers. She says her neckline, shoulder and chest wall don't look symmetrical, and her shirts, jackets and coats don't quite fit right. Instead of the prosthesis, she often uses a shoulder cap so that her clothes fit better, and her shirt and coat don't feel as if they're falling off her amputated side.

Cables, Batteries and Motors, Oh My!

I hope these profiles help to demonstrate how people with unilateral upper-limb loss differ and how their prosthetic needs also vary. I also hope the stories help clarify why one kind of device is not suitable for all, why a person may choose to use different devices throughout the day, and why prosthetics are so incredibly useful, even if they're not used all the time.

The devices we've described have radically different appearances, motion segments and power sources (actuators) to move and control the amount of motion. Some devices are called "passive." The muscles are moved by something or someone else. Others are "active" — you move the muscles yourself

to operate the device. Someday, we'll have systems connecting directly to a nerve, or even the brain, powered by nerve impulses. Most of our current electrical systems use traditional motors, but in the future, we won't use motors as we understand them at all. Instead of motors that spin, researchers are developing artificial muscles with interlocking fibers that shorten when they receive an electrical current and lengthen when the current is stopped. And they use fuels such as peroxide, though they still need some electrical systems and microprocessors.

Just as those who developed mechanical cable systems early in the 20th century could only imagine where advancements in technology would take us, our high-tech crystal ball of today is just beginning to give us a glimmer of what the future holds in the way of prosthetic developments. Looking to the more immediate future, our next article will highlight the needs of bilateral upper-limb amputees and discuss how nerve transfers and targeted muscle re-ervation is becoming a first step toward better connecting the brain to prosthetic devices. ■

"My interest is in the future because I am going to spend the rest of my life there."

— Charles F. Kettering, inventor

