State-of-the-Art
Upper-Limb Prosthetics Technology

While prosthetists and patients eagerly await the results of the Defense Advanced Research Projects Agency (DARPA) Revolutionizing Prosthetics 2009 (RP2009) initiatives, science fiction is meeting science fact right now in today's clinical practice. This article explores some of the upper-limb technologies that are commercially available now or are coming to market very soon.

By Miki Fairley

The Cool Connection

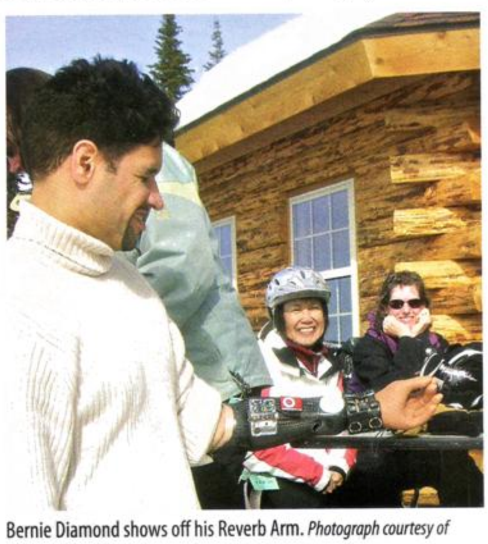
Who says prostheses can't be cool? Not Bernie Diamond, who sports an iPod-enhanced prosthetic arm when he works out or takes to the ski slopes.

Chris Lake

Diamond had an inspiration: Why not have an activity-specific prosthesis that would allow the user to take along his or her favorite music? Diamond took that idea to his prosthetist, Chris Lake, CPO, FAAOP, clinical director of Advanced Arm Dynamics' (AAD) Southwest Center of Excellence, Irving, Texas.

Lake and the staff enthusiastically accepted the challenge, researching miniature speakers and various types of MP3 and iPod interfaces. The current version—dubbed the Reverb Arm—provides a clip that allows any iPod to be docked into it. "The structure of the [arm] includes a cavity for the speakers so that they can reverberate accordingly," Lake says. "The modification to place the speakers inside the prosthesis can be done to any level of amputation as long as room allows." Since room was available in Diamond's prosthesis, "We elected to place a small amplifier inside for visual and audio effects."

The next version of the arm will incorporate an onboard iPod Touch, Lake says.



Bernie Diamond shows off his Reverb Arm. *Photograph courtesy of Advanced Arm Dynamics Inc.*

Diamond loves the quality of the sound. Besides using his "enhanced" arm during his fitness workouts, he also provided "music in the mountains" for fellow skiers during an Idaho ski trip last winter.

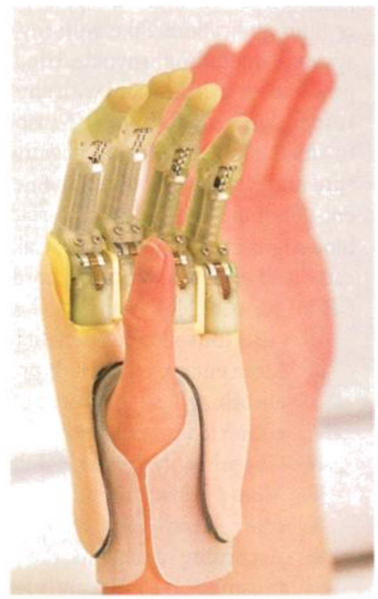
"It's really, really cool," Diamond says, "So many people when they think of an amputee think of someone severely disabled—with a hook or just a passive hand. But there are some really cool prosthetic devices out there."

Although adjusting to the loss of an arm or a hand is a huge, complex physical and psychological task, Diamond firmly believes that a missing limb doesn't have to stop a person from being cool, enjoying life, and having a great time.

New Territory in Partial-Hand Technology

While Lake is all for adding a little fun to the prostheses he creates, he also has a keen eye toward function and points out a vital gap in partial-hand prosthetic technology: solutions for amputations at the metacarpophalangeal joint level. The Otto Bock SensorHand™ and the Motion Control shortened ProHand have been available for traditional transcarpal-level amputations, while amputations at or proximal to the mid-metacarpal level can be addressed by Touch Bionics™ ProDigits™, Lake notes. "The big challenge to date is that there was no functional component

Shawn Swanson, OTR/L, works with an upper-limb-prosthetic patient during an occupational therapy session. *Photograph courtesy of Advanced Arm Dynamics Inc.*



Above: Touch Bionics ProDigits.

Left: Vincent finger prosthesis with dynamic muscle contoured interface.

available for amputation levels at the metacarpalphalangeal joint that provided both a functional and aesthetic return although the vast majority of partial-hand amputees are at this level," he says.

However, the Vincent System from Medical Technic Group, Freiburg, Germany, headed by Stefan Schultz, PhD, has developed the Vincent finger component, and under Lake's direction, AAD is the sole clinical partner in the United States and comprises one of a handful of specialist teams worldwide chosen to work with and further develop this technology. Lake says, "I was chosen based on my work with partial-hand prosthetics…as well as my PhD endeavors through the University of Strathclyde [Glasgow, Scotland] on partial-hand fittings." AAD will continue clinical work after the commercial release of the product.

Lake says that unlike some of the other designs, the Vincent finger includes metal rather than plastic construction, a 5 mm attachment-plane-to-joint-axis build height, overall reduced size, increased torque, and a stable attachment configuration. The Vincent componentry will be available at the end of 2010 to upper-limb specialists specifically trained in partial-hand fittings.

Another significant challenge for designers of partial-hand prostheses is socket design, Lake points out. "As prosthetists, we seem to err on the side of encapsulating the anatomy." He stresses that it is important to recognize that the hand is "a vital sensory organ for the body," and notes a design shift toward a frame-type socket that provides stability while leaving more flexible areas of the residual hand free (see frame socket pictured above).

Of interest to clinicians is the fact that partial-hand amputations far outnumber amputations distal to the wrist, Lake points out in an article, "Experience with Electric Prostheses for the Partial Hand Presentation: An Eight-Year Retrospective," published in the *JPO: Journal of Prosthetics and Orthotics*, February 2009.

Referencing a study by Dillingham, et al., "Limb Deficiency and Amputation: Epidemiology and Recent Trends in the United States," (*Southern Medical Journal,* 2002; 95:875–883), Lake notes that approximately 18,496 individuals are born without an upper limb or lose a limb due to disease or trauma. Of these, nearly 17,000 are amputations or congenitally deficient losses distal to the wrist. "What this means from a clinical standpoint is that professionals in our field are focusing their efforts each year on the needs of fewer than 2,000 individuals who are at a high level of upper-limb deficiency, and this minority of amputees comprises the bulk of our typical clinical experience," Lake notes in the article. "Meanwhile, there is a huge pool of partial-hand-level amputees who would no doubt appreciate and greatly benefit from effective prosthetic options if these options were only available to them."

Learning to use a partial-hand prosthesis seems to be fairly intuitive for most patients, Lake says. The continued development of smaller componentry to fit more functionally and aesthetically into the prosthesis is another positive trend. With the advances in technology and other treatment aspects, Lake believes that partial-hand amputations "will be commonly fit in the coming years."

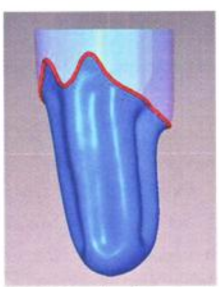
High-Fidelity: Futuristic, Versatile

Randall Alley

Imagine an interface that can be used for prostheses and orthoses in upper- and lower-limb applications alike, with any control system—including myoelectric, body-powered, or hybrid—and with any type of suspension system, from self-suspending to auxiliary suspension to negative pressure and elevated vacuum. The new, patent-pending High-Fidelity interface from biodesigns inc., Santa Monica, California, can do all of this and more, according to inventor Randall Alley, CP, LP, FAAOP, biodesigns' CEO and chief prosthetist.

Alley lists the following benefits of his High-Fidelity interface:

- More energy efficient. It preserves motion rather than absorbing it so that more of the wearer's input is converted to prosthetic output.
- Considerably greater stability.
- More feedback to the user.
- More effective heat dissipation.
- According to patients, the perceived weight of the prosthesis is significantly less.



CAD/CAM-rendered image of High-Fidelity femoral interface.

The design incorporates a feature called "vector-enhanced compression and tissue relief" (VECTR), in which a force vector applies specifically targeted compression areas along the long axis of the intrinsic or target bone.

"In between these longitudinal areas of compression that travel nearly the entire length of the bone are areas or windows—depending on whether the interface is a solid-body or an open cage-style interface, respectively—where soft tissue can flow out of the way or out of the interface entirely," Alley explains. "This allows increased compression on the intrinsic bone...above that in a traditional hydrostatic socket." Alley emphasizes that the amount of compression must be very precise. "That is why I have applied for a patent and why I utilize sensors to analyze a safe compression level. Above a certain level, you lose adequate blood flow; below a certain level, you lose the benefits."

At press time, the methods used to create the High-Fidelity interface are proprietary; however, Alley explains that sophisticated sensors analyze the intrinsic environment at the interfacial boundary and deeper within the soft tissue, ensuring that the increased intimacy of the fit is safe for the wearer.

The design is involved in two clinical studies as part of a larger project by DEKA Research and Development, Manchester, New Hampshire, founded by Dean Kamen, and DARPA; and

High-Fidelity humeral interface with VECTR modification. *Photograph courtesy of biodesigns inc.*

the U.S. Department of Veterans Affairs (VA). "The goal of the DEKA/DARPA project is to create a production version of the DEKA Luke Arm as featured on *60 Minutes* and for which the High-Fidelity interface design and its VECTR concept forms the foundation for the socket interface utilized in this project," Alley says. The goals of the VA study include optimizing the DEKA Arm system with the High-Fidelity interface, (with DEKA enhancements), as one unit, as well as optimizing the interface and the fitting process...." Alley is charged with the initial training of key VA clinicians at the designated study sites in the proper design and fitting of his interface and is working with Next Step O&P, Manchester, New Hampshire on the DEKA/DARPA project.

The Luke Arm is named after *Star Wars* hero Luke Skywalker, whose bionic prosthesis has been inspiring engineers and inventors to try to duplicate it in real life.

To view a video of the Luke Arm in operation, visit www.youtube.com/watch?v=r0_mlumx-6y

Disclaimer: This project is sponsored by the Defense Advanced Research Projects Agency and the U.S. Army Research Office. This information does not necessarily reflect the position or policy of the government; no official endorsement should be inferred.

The i-LIMB Hand: Revolutionary Technology

Mark Ford

A dazzling breakthrough in upper-limb technology, the i-LIMB™ Hand from Touch Bionics™, Livingston, Scotland, is the world's first commercially available fully articulating prosthetic hand. The i-LIMB Hand offers both dual-site and single-site alternating strategies for myoelectric input from residual-limb muscles. Each individual digit has its own motor, power train, and load system, explains Mark Ford, Touch Bionics' director of North American sales and marketing.

The time between a muscle contraction and hand movement is less than one-100th of a second, according to Ford, due to the speed of processing the myoelectric signal through the control chip.

"The control board design enables the user to control all the digits separately or simultaneously, depending on their level of training and personal capabilities," he adds. The design also includes a stall feature. By pressing the desired finger against a firm surface and contracting the remaining fingers, the desired finger will be locked into position for use in such activities as one-fingered computer typing or using an ATM.

Bilateral amputees can effectively use the i-LIMB on both residual limbs, and i-LIMB Hands have been fitted on several

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patients who have undergone targeted muscle reinnervation (TMR) surgery performed by Douglas Smith, MD, professor of orthopedic surgery at the University of Washington, Seattle, according to Ford. TMR surgery restores the nerve function from the remaining arm nerves to chest or upper-arm muscles, which can then provide accurate signals for controlling the hand, wrist, and elbow of the prosthesis.

For more information on TMR surgery, see "Targeted Muscle Reinnervation: The Future Is Now," The O&P EDGE, *December 2007. For more information on the i-LIMB Hand and Touch Bionics, see "Form and Function: New Hand Looks, Acts Like the Real Thing,"* The O&P EDGE, *August 2007.*

Based on the feedback from users and prosthetists, the i-LIMB has undergone several improvements over the past year. Ford says it has been improved to include new strength features to support heavier lifting, new thumb mounts for greater durability, new flat tips for fingers to allow precision lifting of parts, and smoother gearboxes and motors for enhanced digit movement. Plans are underway to develop an i-LIMB able to use even more myoelectric sites, Ford adds, thus increasing control over the individual digits.

To view a video of the i-LIMB Hand, visit www.touchbionics.com

ProDigits

Touch Bionics' newest product, waiting in the wings for commercial release, is ProDigits™. Ford says that ProDigits is currently in the beta field-testing stage in cooperation with several independent O&P facilities and some Hanger Prosthetics and Orthotics offices, as well as Brooke Army Medical Center, San Antonio, Texas. Improvements are being made based on users' and prosthetists' testing feedback.

ProDigits provides a partial-hand amputation solution via individually powered myoelectric control for any one or up to five prosthetic fingers. Candidates must have an amputation at the transmetacarpal level or higher of one or more fingers. It is possible to provide a ProDigits prosthesis for candidates who only have a portion of a remaining finger, but this affects the aesthetics of the overall prosthesis, Touch Bionics notes.

ProDigits can be controlled by either force-sensitive-resistor (FSR) or remote electrodes. Although the control system is based on traditional myoelectric technology, Touch Bionics has developed Bluetooth®-enabled solutions to help clinicians adjust finer motor functions to a specific user. Like the i-LIMB, ProDigits also provide a stall feature for single digits for typing, telephoning, and other everyday tasks.

Motion Control Reaches Ahead

With its newest release—the Utah Hybrid Arm—Motion Control has made a "simpler, lighter, and more affordable arm," according to Motion Control President Harold H. Sears, PhD. "Although evolved from the U3 arm," Sears says, "it eliminates the electric elbow drive while retaining the high-tech myoelectric controls of the hand and wrist, plus the electric elbow lock."

The Utah Hybrid Arm represents Motion Control's latest innovation to the Utah Arm product line since the U3 Plus. Brought to market in 2007, the U3 Plus introduced additional comfort benefits for the wearer and marked the company's biggest step forward since the microprocessor transition in 2003, according to Sears.

"The silent freeswing feature disconnects the drive when the elbow drops to full extension so that the elbow swings effortlessly and naturally while walking," Sears says. "The dual-stage lock allows the U3 Plus to lock at an infinite number of positions, compared with the 22 possible with the U3."

Water and dirt pose a huge challenge to those using electronic prostheses in a wide range of environments. Motion Control's vanguard in the water war is its Electric Terminal Device (ETD), the first truly water-resistant ETD, Sears notes. Coming soon, Sears says, is a water-resistant EMG sensor—or "pre-amp"—highly useful in the sweaty socket environment.

Protecting the electronics by encapsulating them within the device involves incorporating what Sears

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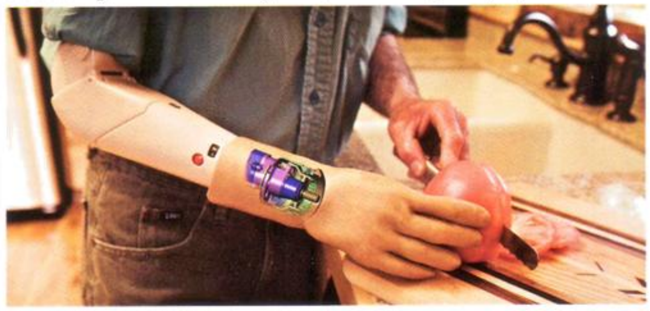
describes as "fairly simple technologies—the challenge is how to apply them." Materials, casing design, sealing up borders where the casing halves come together, and O-rings all play a role.



InHand Wrist Rotator. *Photograph courtesy of Motion Control.*

Another innovation that has enjoyed considerable clinical success, according to Sears, is the InHand Wrist Rotator. Before its development, users of wrist rotators were often frustrated because their rotators lacked enough power and torque to perform most active functions and have thus been primarily used for prepositioning the hand/terminal device. For instance, pouring cream in a cup of coffee using the rotator is an active function. The InHand Wrist Rotator, by providing substantially more power and torque than other current wrist rotators, enables users to increase the number of active functions they can perform, Sears notes.

While the current InHand Wrist Rotator can only be used with Motion Control hands and terminal devices—each device requires its own rotator—the new InHand Wrist Rotator solves this problem. The rotator will be mounted inside the forearm of the prosthesis and will rotate any terminal device or functional hand, regardless of manufacturer. According to Sears, the new rotator will be available commercially soon.

Motion Control's other enhancements include a new lithium ion battery pack and the availability of Bluetooth® wireless programming for all products. Since Bluetooth frequently experiences connectivity issues due to competing computer programs or other interference, customers wanted to keep the hardwire adjustment as well, Sears says. "So, with Bluetooth as an add-on plug-in, prosthetists can still use hardwire as backup."

At the prosthetists' discretion, computer-savvy users can make their own adjustments through their computer and a user interface kit, thus avoiding appointment and travel time, and expense.

Thought-Controlled Technology

Thought-controlled prostheses take another step forward as a pioneering surgical technique teams up with the latest in upper-limb device technology.

One of these advanced device technologies, to be launched commercially within a few weeks of this writing, is Otto Bock's DynamicArm® TMR for transhumeral and shoulder disarticulation amputees who have undergone TMR surgery.

The elbow function is the same as the myoelectric DynamicArm's; however, the TMR version has been modified to receive eight signal inputs, explains Kristen Knox, senior market manager for upper-extremity prosthetics and the C-Leg® for Otto Bock HealthCare, Minneapolis, Minnesota. "The TMR surgery

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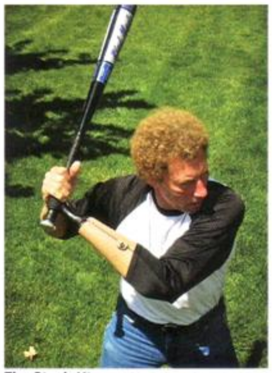
Terminal Devices: Passion Drives Development

When Bob Radocy lost his left hand about four inches below the elbow in a car accident in 1971, he found himself frustrated and dissatisfied with the prosthetics technology available at the time.

He formed TRS, Boulder, Colorado, in 1979 to develop specialized, activity-specific devices for adults and children—ones which enable upper-limb amputees to compete in high-performance sports as well as simply enjoy a variety of recreational activities.



The Pinch Hitter. *Photographs courtesy of TRS.*

Radocy is highly enthusiastic about TRS' newest concept development, demonstrated in three recently introduced devices: the baseball Pinch Hitter, the golf Eagle, and the Power Play for ice hockey. Some of the players on the U.S. Paralympics team are using the Power Play, and the device will likely play a role during the 2010 Winter Games in Vancouver, Canada.

The Eagle.

The Power Play.

"With these, we have started a whole new range of sports and recreation activity-specific terminal devices that don't require cables and are designed to store and return energy," Radocy says. "They are not electric or externally powered in any way, and they don't fit into a traditional body-powered category. A unique design combined with some newer materials technology is enabling us to duplicate anatomical joint motions that we have never been able to do before."

Duplicating the biomechanics of the natural limb is essential for some activities, Radocy points out. "Most prosthetic limbs don't provide the degrees of freedom a person needs to be truly bimanual when swinging a baseball bat, a golf club, or a hockey stick. We have created unique flexible couplings out of synthetic polymers that not only provide the degrees of freedom needed for those kinds of activities, but also, for the first time, we have been able to create energy-storing devices."

Just as energy-storing prosthetic feet use an external force—the user's body weight—to create energy potential and return to enable more effective walking, these upper-limb devices store and return energy to help users perform activities more naturally—and thus to be truly bimanual, Radocy explains.

Terminal Devices in Development

TRS has been working with a graduate student at the Massachusetts Institute of Technology (MIT), Cambridge, to develop a specialized golf energy-storing device for persons with a transhumeral amputation, Radocy says. The prosthesis uses a short sports socket terminating right at the end of the user's residual limb, with a unique, flexible, energy-storing coupler that eliminates the elbow and forearm entirely. The user can then swing a golf club without using a traditional prosthesis. The lighter-weight, highly functional, energy-storing coupler is engineered to help control the plane of the golf swing, storing energy on the back swing and returning it at the bottom of the down stroke.

Although TRS terminal devices are designed to fit on standard prostheses, for certain activities, a short sports prosthesis provides greater performance and control, Radocy says. O&P EDGE

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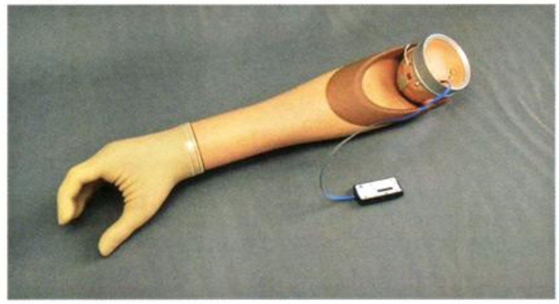
essentially allows for thought control of the prosthesis by reinnervating nerves to an existing muscle. One of the major benefits of TMR is having more than two degrees of freedom that can be controlled simultaneously, providing additional function to the user," Knox says.



Otto Bock's DynamicArm with eight-axon interface. *Photograph courtesy of Otto Bock HealthCare.*

Several patients in the United States have been fit with the TMR version during beta-testing field trials. These patients, fit about a year ago, have recently received the updated version of the software.

One of these patients, Hank Esmond of Indiana, an electrical lineman, underwent a left shoulder disarticulation and a right transhumeral amputation after 7,200 volts of electricity shot through his body, according to an article in *Business Wire*, June 5, 2009, and WANE-TV, Fort Wayne, Indiana.

"As with all TMR procedures, nerves are rewired onto muscles that have limited function because of limb loss," said Pat Prigge, CP, upper-extremity specialist with Advanced Arm Dynamics' Midwest Center of Excellence, Waterloo, Iowa, quoted by *Business Wire*. "During the healing phase of the rewiring process, we are able to use the new Otto Bock DynamicArm TMR so that we can fit patients earlier in the rehabilitation process. We can customize the input devices and control schemes in order to maximize their potential and continue to make updates while the new TMR sites get stronger—a process that will take up to eight or nine months." AAD worked with Sam Santa-Rita, CP, LP, owner of SRT Prosthetic and Orthotics, based in Fort Wayne, Indiana, in fitting Esmond with the DynamicArm TMR on his shoulder disarticulation side.

"This new technology allows me more independence and more self-sufficiency to take care of things on my own," said Esmond, quoted by *Business Wire*.

There's no doubt that the upper limb is the focus of some of the most exciting developments in prosthetic technology in recent years, and this is only a sampling of what's out there in this rapidly changing world. And while the O&P industry eagerly awaits the fruits of the DARPA RP2009 upper-limb projects, manufacturers and technology companies aren't waiting to bring their own products and enhancements to market. These technologies are just the first wave of the future. O&P EDGE

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