# Looking Ahead at Computer-Controlled Knees

*by David Boone CP, MPH, PhD*

I enjoy driving my 1963 Plymouth. It is a very simple and powerful automobile. Over the years I've rebuilt it entirely and can verify that there are very few wires or controls and no computer controlling the big V-8 under the hood. The mechanisms that make it run are obvious, and when everything is just right it works relatively well. While I love my old car, in truth it is not as efficient, safe, quiet or trouble-free as our family car, a 2005 hybrid Prius. This reminds me very much of the way prosthetic knees are changing.

Computers are a big part of the prosthetics revolution, and they are raising new standards of function for prosthetic knees. Further significant improvements in knee function will mostly come from ever more sophisticated control systems, like the microprocessor. The microprocessor is the tiny decision-making part of the computer that follows a predetermined set of instructions to control the functions of the knee. Sensors in the knee provide information to the microprocessor to determine what the knee should do.

David Boone and his 1963 Plymouth

Many of the key requirements for more advanced prosthetic knee control have been understood for decades, and in the past, ingenious mechanical devices such as the Mauch SNS and Hydracadence knees were developed to provide prosthetic knee function with no “intelligent” control. Unfortunately it was extremely difficult to extend their functions further. For more sophisticated control, researchers turned to computer programs. In the 1970s and ’80s, Professor Woodie Flowers at MIT, and his many graduate students, pushed the frontiers of knee control. Refrigerator-sized computers operated a tethered knee in a preview of things to come. All the basic ideas were there, even if suitable microprocessors were not.

By the late 1980s, researchers and engineers from the Kobe Steel Company in Japan developed and introduced the Intelligent Knee™, the first commercial version of a prosthetic knee with computer control. I was amazed one day in 1989, by the sight of a prosthetic knee user on a treadmill, transitioning seamlessly from a slow walk to a fast run and back again. This “intelligent knee” adjusted the “swing phase,” changing the timing of how the leg would swing with each step. It was adjusting itself instantaneously to the changing needs of the user. Perhaps most significantly, there were no connecting wires. The computer-controlled knee was self-contained: mechanics, microprocessor controller and battery-powered.

Soon after, researchers in Canada created a prosthetic knee with the key additional function of computerized “stance phase” control. Most people think that the way a knee bends is its main function, but it is just as important to control how the knee does not bend when the user is standing on it and expecting it to support their body. The advantages of being able to control both how the knee should flex and not flex with an integrated computer controller created opportunities for significantly advancing function and safety, leading to the development of the Otto Bock C-Leg™.

Another breakthrough advance in the stance control of prosthetic knees has been to provide power to extend or straighten the knee under computer control. The Össur Power Knee™ has achieved this goal by creating a control system with compact electric motors powerful enough to lift the user step-over-step up stairs.

From key developments in swing and stance control, every major prosthesis component manufacturer has developed or is developing its own computer-controlled knee. What is available now is already remarkable, but these are just first steps and it is certain that improvements in knee function will accelerate. Looking at the state of development of computer-controlled knees, what can we tell of the future?

For developers, much of the excitement about computer control for knees comes from the ability to reprogram the microprocessor with new software. Scientists can apply new insights about walking with prostheses and work with computer programmers to create new functions with little or no change to the hardware. With computer control of knees we can much more effectively improve the function of a new design by simply changing the instructions for how the knee should bend, and under what circumstances. New versions of computer-controlled knees will be released that are basically software updates to existing knees. Some of these improvements will even be uploaded in ways that don't require the knee to be removed or replaced. Since there is a very high cost for developing the knee hardware, manufacturers can be sure to get the most out of their knee designs through continued software improvements like these.

The most significant attribute of more advanced computer-controlled knees is the ability of the knee to dynamically adapt to the environmental demands and the functional needs of the user. This adaptive control will be the hallmark in the coming generation of prostheses. For the user, this means that the prosthesis will automatically adjust its function for changing demands, such as walking up or down hills, or for differences in the way the user is performing. The more the knee appropriately adapts, the better it feels to the user. An important potential for adaptive control of knees is improved safety. With computer control, the modern prosthetic knee can sense how the user is moving, and, detecting danger of falling or slipping, it can react to keep the knee from contributing to a fall. Software will be built into knees to help users recover from stumbles before they fall. It is becoming clear that computer control is useful not only for optimizing performance of highly active people, but can also provide greater safety for less active users.

Comfort is always a goal in prosthetics research and development because it is a high priority of the prosthesis user. This is true for knee design as well. One tends to think about comfort in terms of the interface of the prosthesis – how soft or supportive it is, but comfort is also very much determined by dynamic conditions. For example, hip or lower-back discomfort may be aggravated by a prosthetic knee that requires abnormal use of the muscles to stabilize or move the knee. Conversely, adaptive controls can decrease the demands on the users required to achieve their desired motion and result in increased comfort.

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A human walks with great efficiency because each step is in delicate synchrony with the rest of the body. In many ways, emulating this efficiency is the ultimate challenge for the prosthesis designer. An important facet of efficiency is alignment stability. The prosthesis user is in a fine balance on the leg most of the time, and very little additional power is needed for most tasks. Powered actuation (movement) need not provide all the thrust to push a person along, but can be used very efficiently for reflex-like actions to actively maintain that fine balance of stability. Of course, all this takes electrical power, and designers need to make knees energy-efficient to minimize the size and weight of batteries and time to recharge. Using a technique called energy harvesting, future computer-controlled knees will regenerate some of the power they need in the way hybrid cars recover "waste" energy from applying the brakes. The swinging pendulum of the lower leg can generate a little power to be returned to the battery with each step.

Today, computer-controlled knees use sensors to continuously and rapidly measure the balance of forces on the knee and the speed and direction of knee movement. From these measures, the program in the microprocessor makes decisions about what the user is doing and how the knee should best respond. With the computer controllers there is a great opportunity to add more inputs to this decision-making process. Neural control of prosthetic knees refers to using nerve impulses or even brain activity that can be sensed by the prosthesis controller and interpreted as the user's intent.

The computer in the computer-controlled knee cannot on its own ensure a high level of function. Computer-controlled knees have the same mechanical problems as traditional knee designs. The knee joint must withstand extremely large mechanical forces but be able to move freely in an instant. New materials will improve the durability of the moving parts, and today manufacturers are working on new miniaturized electrical, hydraulic and magnetic controls for the next generation of computer-controlled knees. New knee designs must also be applied and adjusted for the control functions to work properly. Incorrect programming of settings for the user is the most obvious potential problem, causing the knee to bend at the wrong time or not at all. There are other, more subtle clinical factors the prosthetist must consider. The most important clinical factor for the knee is the alignment of the prosthesis. Improper alignment of a computer-controlled limb results in the computer receiving conflicting information about the function of the limb, resulting in erratic or incorrect function. Advanced alignment techniques will be vital to ensure proper function of the next generation of prostheses.

Will there still be a use for non-computer-controlled knees? Absolutely. Every user has different needs, so the best solution for one prosthetic knee user is never going to be the best choice for all. The considerations for knee selection are based on the specific needs of the user, affordability, robustness and personal preference for how it "feels." Computer-controlled knees are not universally the best choice. The control systems available may be specifically designed for certain kinds and levels of activity that should be matched to the user with care. For a person who will not use the functions of a certain knee, there is little justification for having controls that are never employed, and there may be extra burden on the user associated with having the controls (such as keeping the knee charged). The prosthetist's individual evaluation with the client's input should be the final word on what is a suitable knee.

Summer is over and the weather is starting to turn cool and damp. I think it may be time to adjust my carburetor. That's kind of fun for me, but I don't think anyone should ever be quite as nostalgic for their old mechanical knees as I am about my old car. ■

## About the Author

*David Boone CP, MPH, PhD, is Chief Technology Officer with OrthoCare Innovations.*

## Computerized Knees on the Market

**Endolite**
Intelligent Prosthesis Plus
Adaptive 2
www.endolite.com

**Freedom Innovations**
Agility MPC Knee
Plié MPC Knee
www.freedom-innovations.com

**Ossur**
Rheo Knee
www.ossur.com

**Otto Bock HealthCare**
Otto Bock C-Leg
Compact
www.ottobockus.com

**Seattle Systems**
Seattle Power Knees (3 models include Single Axis, 4-bar, Fusion)
www.seattlesystems.com

**Victhom & Ossur**
The Power Knee
www.victhom.com