Jiping He knows all about expectations. He and his colleagues also know the joy of exceeding expectations. Their work is helping paralyzed patients with severe spinal cord injuries to walk again, if only in a limited way.

He is a professor of bioengineering at Arizona State University’s Center for Neural Interface Engineering. The center is part of the Biodesign Institute located on ASU’s main campus. Working with Richard Herman, research director of the Clinical Neurobiology and Bioengineering Research Laboratory at the Good Samaritan Rehabilitation Institute in Phoenix, He’s research team has devised a special treatment regimen. Their original hope was to find a way to help spinal cord injured patients gain the ability to stand up and take a few steps. Such success would have made them happy.

The researchers are much happier today because they have accomplished more than that. Thanks to their innovative treatment, two patients with spinal cord injuries have been able to walk again with the use of walkers.
Finally, the patient walks on the ground using a walker.

The patients in the study began with three months of partial weight-bearing therapy, also known as treadmill training. A harness bears a portion of the patient’s body weight as he stands on a treadmill. Two physical therapists move the patient’s legs rhythmically as the treadmill moves slowly. Over time, the patient begins to move more and more on his own. Gradually, researchers reduce the amount of body weight suspended and increase the speed of the treadmill. Finally, the patient walks on the ground using a walker.

The American Spinal Injury Association divides spinal cord injuries into four categories: A, B, C and D.

Injuries in category A are complete. The patient has no function at all below the injury site. Injuries in categories B, C and D are partial; the patient retains some sensation, motor function, or both.

He and Herman focused their work on patients in category C, who have limited motor function. The scientists wanted to know if these patients could benefit from partial weight-bearing therapy combined with electrical stimulation.

The researchers turned on the device a week later, and the patients returned to treadmill training. When patients reached their pre-surgery level of activity, the researchers turned on the stimulation device during training sessions.

With electricity flowing into their spinal cords, patients walked faster and further, and for longer periods of time. Their sense of effort dramatically decreased. “On an effort scale of 0-10, it was a seven or eight with no stimulation,” He says. “With stimulation, it was a three or four.”

When the stimulation was turned off, patients could not do as much as when it was on, but still more than before the surgery. Herman and He were baffled. How could electrical stimulation be affecting sense of effort?

The ASU researchers found that over time the patients improved their gait, or walking pattern. Their hips and knees moved more smoothly. Their walk looked more and more like a normal walk. But the energy and effort needed to walk were considerable. It never became easier. “This is the singular key,” Herman says. “But it didn’t hit us for a long time.”

Basic biology provides part of the answer. Cells use the oxygen we breathe to break down complex molecules, such as carbohydrates and fats, into carbon dioxide. The energy released during that breakdown is used to power cell activity such as muscle movement. The amount of oxygen, and thus energy, a person consumes can be determined by looking at the air that person breathes out.

When stimulation was turned on, patients could do more as they had more energy. The ASU researchers found that the larger the number of nerves stimulated, the more energy the patients saved.

Willis studies biology at the sub-cellular level. He does not usually do whole body experiments. But when the request for help was made by Herman and He, Willis had more interest than other ASU professors with experience in this area. “It was serendipity. The other ASU investigators with more experience in these issues wouldn’t have paid attention to the carbon dioxide production,” Willis explains.

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Exhaled air contains carbon dioxide, nitrogen, and other gases in addition to oxygen. Carbon dioxide levels depend on the fuel the body uses. That fuel might be in the form of carbohydrates or fat.

Willis found that the amount of carbon dioxide exhaled by the patients sharply decreased when the electrical stimulator was on. This suggested that fat was making a much larger contribution to the fuel supply— or that the stimulator reduces reliance on carbohydrates as fuel. “It was an extremely exciting finding,” Willis says. “All kinds of possibilities came to mind.”

Willis explains that the human body mostly breaks down fat when people work at an effortless rate. When people work harder than normal, such as during strenuous exercise, carbohydrates are the main fuel.

The ASU scientist had performed an experiment on himself seven years ago. Willis measured his exhaled air as he walked on a treadmill, changing the speed in 1 mph increments every five minutes. Willis found that he used almost exclusively fat for fuel when walking at 3 mph. When he saw the data from the spinal cord patients, the results of that experiment came back to him.

Willis repeated his experiment with other able-bodied people. He found that when the subjects’ rate of carbohydrate consumption went up, their perception of effort went up by the same proportion. But he found no association between perception of effort and fat consumption rate.

“A person’s endurance limit is their fat stores. At three miles an hour, a lean person can walk a thousand miles or more without eating,” Willis says. “If someone walks faster, three and a half miles an hour, they will be exhausted after about 50 miles. They deplete their carbohydrate stores across all 50 miles.”

Herman and He now believe that stimulation of the patients’ spinal cords caused greater fat oxidation and reduced patients’ sense of effort, making them more similar to able-bodied subjects. But they don’t yet know why the electricity had this effect.

The two patients in the original study have done remarkably well. One uses his walker to go to the post office and grocery store, and can even step up onto a curb. Herman and He are looking for a third patient, and they want to expand the study to another 12 people.

In the meantime, all three researchers are working on a number of related projects. For example, since moving a patient’s legs during treadmill training can be exhausting for a physical therapist, the researchers have developed and filed a patent on a gait training assistant device. Willis also continues to work with able-bodied subjects to learn more about the basic physiology of locomotion. “When you get a clinical benefit, everyone sees how exciting it is and you get the public’s attention. To try to address scientific questions is a little bit more challenging,” He said.

“At the same time, that’s what we’re here for—to find out how to solve those mysteries. We have quite a few questions we want to address.”

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