Paul Thacker, who was paralysed from the chest down in a snowmobile accident, can walk again using an exoskeleton that has four motors and 15 sensors.

TECHNOLOGY

Mobility machines

Mechanical suits known as exoskeletons can help people with spinal cord injuries stand up and walk away from their wheelchairs — but not without training.

PETER GWYNNE

It's the TedMed conference in 2011, and 37-year-old Paul Thacker grunts a little as he rises to his feet using forearm crutches and plods slowly across the stage of the Hotel del Coronado in San Diego, California. The crowd claps. The teetering walk hardly seems worthy of the applause, especially for a professional snowmobiler who once held the world record for distance jumping, clearing the length of a football field. But this no ordinary walk, because Paul is paraplegic.

In November 2010, Thacker crashed during a practice jump. On his blog, he described his accident as "a little get off", which "left me with a broken back and no feeling from my chest down." But Thacker and others with similar injuries might soon trade in their wheelchairs for 'exoskeletons' — electromechanical ambulatory-assistance devices, like the one Thacker used at TedMed, that enable those paralysed by spinal cord injuries to rise up from their chairs and walk.

Devices that support patients as they walk upright first emerged in the 1990s. But the early versions required overhead harnesses, which limited walking to treadmills. That has changed, and today's exoskeletons are effectively wearable robots that provide the power to enable movement. Commercial exoskeletons produced by Ekso Bionics of Richmond, California, Rex Bionics, based in Auckland, New Zealand, and Argo Medical Technologies in Israel have already reached the market. Another commercial device is soon to be released, and more are in development.

"This is a very exciting time," says José Contreras-Vidal, who specializes in healthcare robotics at the University of Houston in Texas. Early users have already given their approval to the devices. Ann Spungen, an exercise physiologist at the James J. Peters VA Medical Center in the Bronx, New York, has helped patients to use the devices. "I have had wonderful experiences of seeing patients become quite ecstatic," she says. "They love to stand upright and make eye-to-eye contact. Family members come to stand beside them the first few times. Patients then want to walk upstairs."

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SUPPORTED SUPPORT

In some cases, stairs still remain a challenge for exoskeletons. For now, even the exoskeletons need some support, such as the crutches that Thacker used to cross the stage at TedMed. He was using the exoskeleton from Ekso Bionics, aptly named the Ekso.

This device goes over the patient's shoulders — reminiscent of the restraint system on a rollercoaster — and straps across the torso and attaches to the legs and feet. It includes four motors, for the hips and knees, and 15 sensors that keep track of joint angles and a variety of other metrics. A computer in a small backpack-like part of the exoskeleton controls the movements.

The Ekso can operate in three ways. In the easiest one, called FirstStep, a physical therapist uses a remote device to control the steps. At the next level, called ActiveStep, the patient controls the steps through buttons on crutches or a walker. At the high end of functionality, called ProStep, the patient leans forward to get a step started and the exoskeleton's motors take over. At TedMed, Thacker used the basic FirstStep mode. An assistant walked behind him, using a controller wired to the Ekso to drive his steps. She stayed close to him and steadied Thacker when needed.

The Argo ReWalk operates in a similar way. Motors, sensors and a computer control the motion, and forearm crutches help the user to balance. "In Argo's ReWalk, the patient controls the walk, like a toddler losing and then regaining balance," Spungen says. A user presses a button and leans forward as the exoskeleton's electronic and mechanical systems make a step.

Spungen and her colleagues have studied the stepping mechanics of the ReWalk[1]. They measured the vertical ground reaction force — essentially the weight on a foot in the up-and-down direction — during both ReWalk-driven walking and a healthy subject's walking. Someone walking with the exoskeleton typically produces similar forces to normal walking. "The ReWalk simulates natural walking very well, with the heel strike, mid-stance and toe-off," she says.

The ReWalk also helps spinal-injury patients to accomplish some more advanced movements. "It can also climb stairs one at a time," Spungen says. Instead of just swinging a leg forward, the ReWalk can flex the hip and knee enough to lift a leg from one stair to another. When navigating stairs, though, the patient typically uses a forearm crutch on one side and holds a railing on the other side for balance.

Because the technology is so new, research teams such as Spungen's focus on training patients to use it effectively. "Our patients walk 4 to 6 hours per week in three sessions," she says. "They have a learning curve, but the more efficient they get, the easier it becomes. They can walk 140 to 180 metres in 6 minutes generally." At the high end, that's a little more than 0.5 metres per second, and another study has reported similar maximum speeds[2]. Bringing the ReWalk up to the 1.3 metres per second that most healthy people can walk without much stress might be difficult with the patient relying on robotics and forearm crutches.

BIONIC BALANCE

The walking may be slow but the technological progress is rapid. For example, someone using a Rex Bionics exoskeleton doesn't even need to use crutches. The user climbs between Rex's two mechanical legs, is strapped in at the waist and a few points along the legs, and holds onto bars on each side.

One of Rex's arms includes a joystick that controls 29 computer processors. Like the ReWalk, Rex can climb stairs. Compared with Ekso and ReWalk, Rex effectively takes the patient along for the ride — the patient only controls the joystick. Rex moves smoothly and precisely.

Some rehabilitation experts aim to make Rex's joystick unnecessary. Contreras-Vidal and neurosurgeon Robert Grossman of the Methodist Hospital in Houston are exploring how to control the Rex Bionics device in a project called NeuroRex. "We measure brain waves as the patient thinks about moving forward, left or right, and use that information to control the robot," Contreras-Vidal explains. "By looking at different ways of connecting human to machine, we are learning about the human brain and how it adapts to these devices." The scientists say that people who use the system become better at it with practice. "We have seen that the user can improve control," says Contreras-Vidal, who has not yet published his results. "The user is learning how the system operates; the human is in the loop. The robot is becoming part of the human."

INCREMENTAL STEPS

Some spinal cord injuries leave the patient able to stand but not to walk normally. For example, taking steps requires extension of the ankle, which is known as plantar flexion.

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With some exoskeletons, such as the ReWalk, paraplegic patients can climb up and down stairs.

An injury to the spinal cord can make that movement difficult, especially in a way that can support the body weight. Instead of developing a system of motors, sensors and computers to drive that action, Gregory Sawicki, a neuromechanics specialist at North Carolina State University in Raleigh, developed a simple elastic solution. In essence, he uses a spring controlled by a clutch-like system to extend the foot at the right time during stepping[3]. This device seems simple compared with other exoskeletons, but it hints at the broad range of approaches to creating movement for patients with spinal cord injuries.

It is the act of rising from a wheelchair and walking that defines the once unimaginable goal of this field.

Despite their impressive capabilities, exoskeletons come with some limitations. For a start, they are heavy and difficult to transport. Rex weighs 38 kilograms, whereas an advanced wheelchair, such as the Panthera made in Sweden, can weigh less than a quarter of that.

Also, today's exoskeletons for walking do not help patients whose spinal-cord injuries paralyse their arms as well as their legs. So some researchers, including bioengineer Alessandra Pedrocchi at Politecnico di Milano in Italy, focus on arm exoskeletons. She and her colleagues developed a device called MUNDUS that provides power-driven arm and hand motion[4]. It can be controlled by the remaining voluntary muscle activity, by head or eye movement or, like NeuroRex, by brain signals. This system can help the patient to open and close the hand and even lift a cup for drinking through a straw.

Despite such benefits, it is the act of rising from a wheelchair and walking that defines the once unimaginable goal of this field. Exoskeletons might eventually allow a paraplegic to stand easily, balance effortlessly and walk at the same pace as anyone else — or maybe even run along a beach. That's still a vision of the future, but the success of the achievements so far should not be diminished. When asked how he felt at TedMed — after using Ekso just half-a-dozen times — Thacker said: "I just walked across the stage and I'm a paraplegic. I can't really be anything but amazing." ■

Peter Gwynne *is a freelance science writer based in Sandwich, Massachusetts.*

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