Forefront

COLLEGE OF ENGINEERING UNIVERSITY OF CALIFORNIA, BERKELEY

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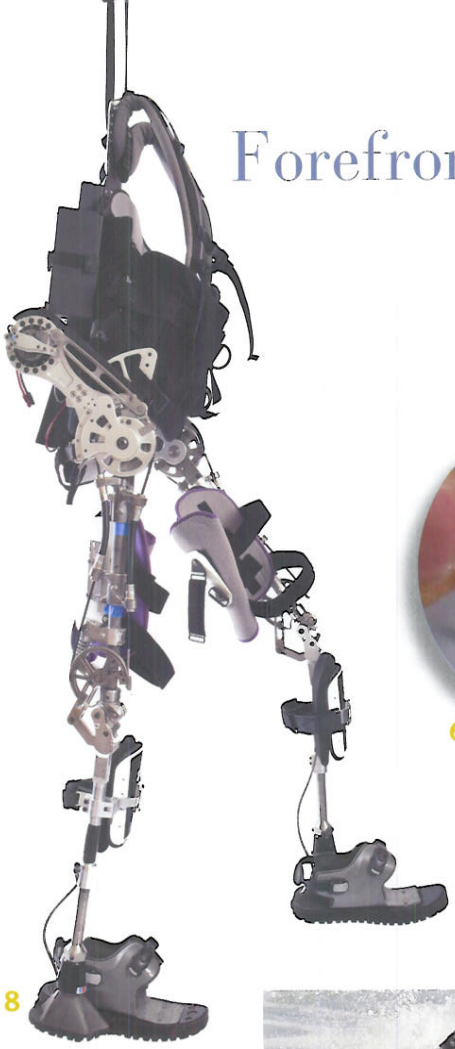
The gift of gait

Robotic exoskeleton restores mobility to paraplegics

Forefront *spring '11* contents



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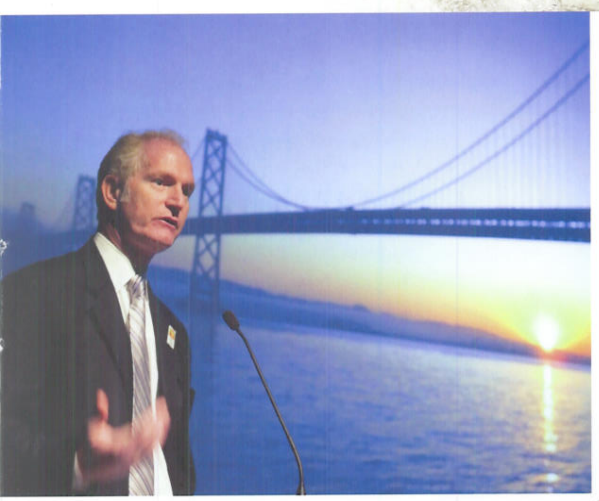
19



12

3

features

departments

On the cover
Read the story on page 8.

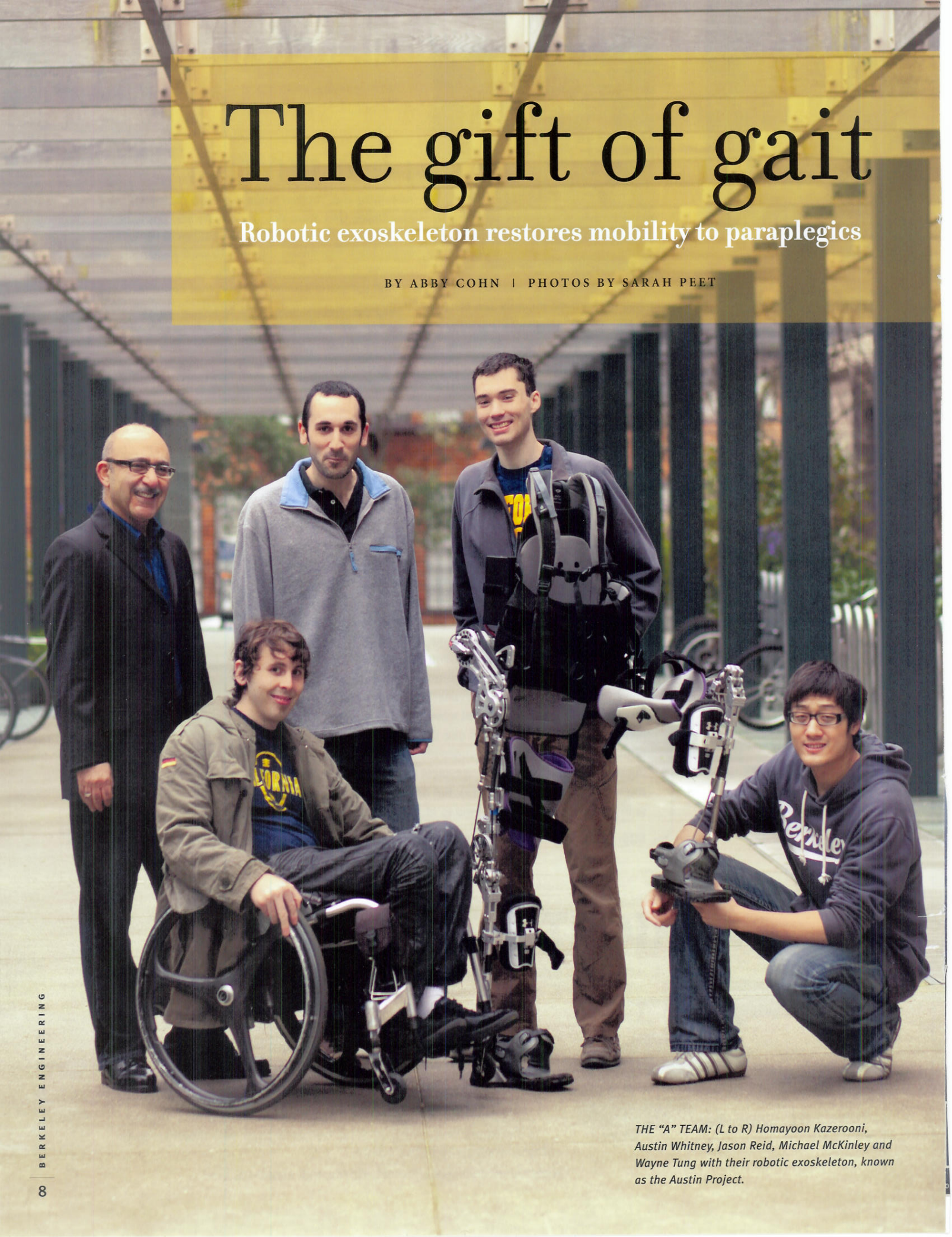
UC Berkeley student Austin Whitney, a paraplegic, walks aided by an exoskeleton that was developed by mechanical engineering professor Homayoon Kazerooni and his team of engineering students.

COVER PHOTO BY SARAH PEET

The gift of gait

Robotic exoskeleton restores mobility to paraplegics

BY ABBY COHN | PHOTOS BY SARAH PEET



THE "A" TEAM: (L to R) Homayoon Kazerooni, Austin Whitney, Jason Reid, Michael McKinley and Wayne Tung with their robotic exoskeleton, known as the Austin Project.

In a research lab deep inside Etcheverry Hall, 22-year-old Austin Whitney straps himself into a robotic suit and achieves the near impossible. Paralyzed from the waist down in a 2007 car accident, Whitney is learning to walk again.

"Are we all powered up?" the Berkeley student asks as the experimental machine lifts him upright and guides his legs through a series of paces across the floor of the Berkeley Robotics and Human Engineering Laboratory. With the device's help, Whitney stood up for his birthday last November and took his first steps as a paraplegic in January, barely two months later.

"There are millions of people around the world who would give anything to be where I am," says the tousled-hair Southern Californian, who graduates this May with a double major in political science and history.

If a Berkeley team led by mechanical engineering professor Homayoon Kazerooni is successful, paraplegics and many others who use wheelchairs may soon be exactly where Whitney is—regaining some ability to stand, walk and live more independent lives. "That's a remarkable achievement for someone in a wheelchair," Kazerooni says.

Still under development, the effort is called the Austin Project in honor of its first human test subject. Austin's researchers have a bold mission: to build a reliable, inexpensive walking machine for everyday personal use. The notion of limiting people to wheelchairs or crutches "is completely unacceptable with the existing technology we have," asserts Kazerooni, director of the robotics lab and a leading expert in "exoskeletons," or wearable robotic devices that enhance strength and improve mobility.

Kazerooni and his graduate student researchers envision robotic legs costing no more than $15,000. At that price, Kazerooni says, they would be roughly equivalent to a motorized wheelchair and within financial reach of many spinal cord injury patients, stroke victims and others with lower-body mobility disorders. The National Science Foundation is funding their work.

"The need is great," says Kazerooni. "What we wanted to see is if there is any way to make machines for people with mobility disorders at a cost far lower than anything [that's been] done before."

A handful of futuristic exoskeletons for paraplegics have been unveiled recently, but Kazerooni estimates their cost at around $100,000 and says they are intended for rehabilitation centers and other institutions rather than for in-home use.

One device, called eLEGS, was hailed as a top invention of 2010 by *CNN* and *Wired* and *TIME* magazines. An artificially intelligent exoskeleton that enables wheelchair users to stand and walk, eLEGS was introduced in October by Berkeley Bionics, a company cofounded by Kazerooni. Kazerooni and two students were developers of the system's controller and human-machine interface. Another exoskeleton, the Israeli-built ReWalk, created a stir when it was featured in a December 2010 television episode of *Glee*. The companies behind both inventions say they are working on versions for personal use.

Kazerooni has long been interested in intelligent devices that assist but don't supplant humans. He previously designed robotic systems for workers who move heavy objects in distribution centers and factories. One of his breakthrough inventions, the Berkeley Lower Extremity Exoskeleton (BLEEX), is a self-powered machine with metal leg braces, a power unit and backpack that enables users to carry heavy loads with ease. Its successor, the Human Universal Load Carrier (HULC), was developed in 2008 and allows people to carry up to 200 pounds. Berkeley Bionics and Lockheed Martin later co-developed a program to fortify HULC for various military and industrial applications. HULC is currently marketed by Lockheed Martin.

Harnessing the potential of robotics to benefit disabled communities has become a driving passion for Kazerooni. "I'm pushing this to another step," says Kazerooni, who would like to complete Austin by mid- or late

2012. If the project proves the feasibility of lower-cost technology, he hopes investors will be interested enough to commercialize it for mass production.

"MAKE THE HONDA, NOT THE PORSCHE"

Austin has a deliberately stripped-down design. It consists of prosthetic steel legs and a backpack-like harness that holds a computer, two small motors and a rechargeable battery capable of running for six to eight hours. "The analogy Kaz [Kazerooni] likes to use is we want to make the Honda, not the Porsche," says Wayne Tung (B.S.'08 ME, MSE, M.S.'09 ME), a 25-year-old graduate student who joined the Austin project at its start two years ago and has stayed on to earn his doctorate because of it.

Built with many off-the-shelf parts, Austin has a limited range of motions. It allows users to stand, walk forward, stop and sit. But Kazerooni believes those few simple maneuvers will be game-changing. "Things don't have to be really fancy. They don't have to dance. They don't have to walk backwards. They don't have to climb ladders. What is important to millions of people is to be upright, mobile and independent," he says.

Dr. Akshat Shah, chief of spinal cord and orthopedic rehabilitation at Santa Clara Valley Medical Center in San Jose, recently began testing an eLEGS at the hospital's rehabilitation unit and has been collaborating with Kazerooni and his Berkeley Engineering lab on Austin. "The technology is very close," he says of these devices. "We're in the beginning of a huge leap forward, a huge paradigm change."

For paralyzed patients, the prospect of standing and walking once again "provides hope," Shah says. "Just the thought of walking down the aisle to get married, reaching up to a top cupboard, walking outside on a beautiful day. This is part of their lives they thought they'd lost."

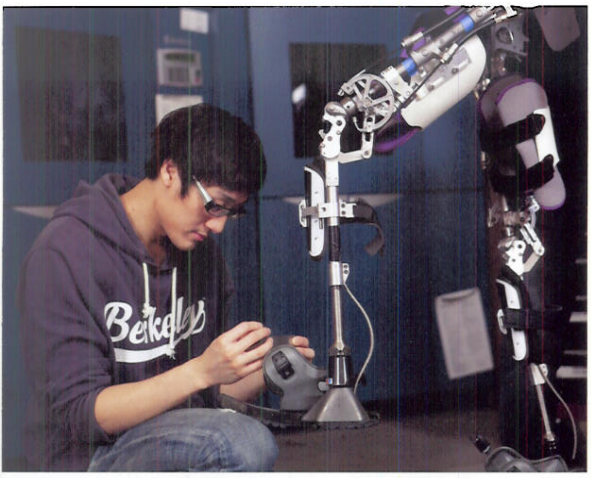
Along with that regained mobility, Austin and machines like it could help patients avoid involuntary muscle contractions known as spasticity, bed sores and the loss of bone density.

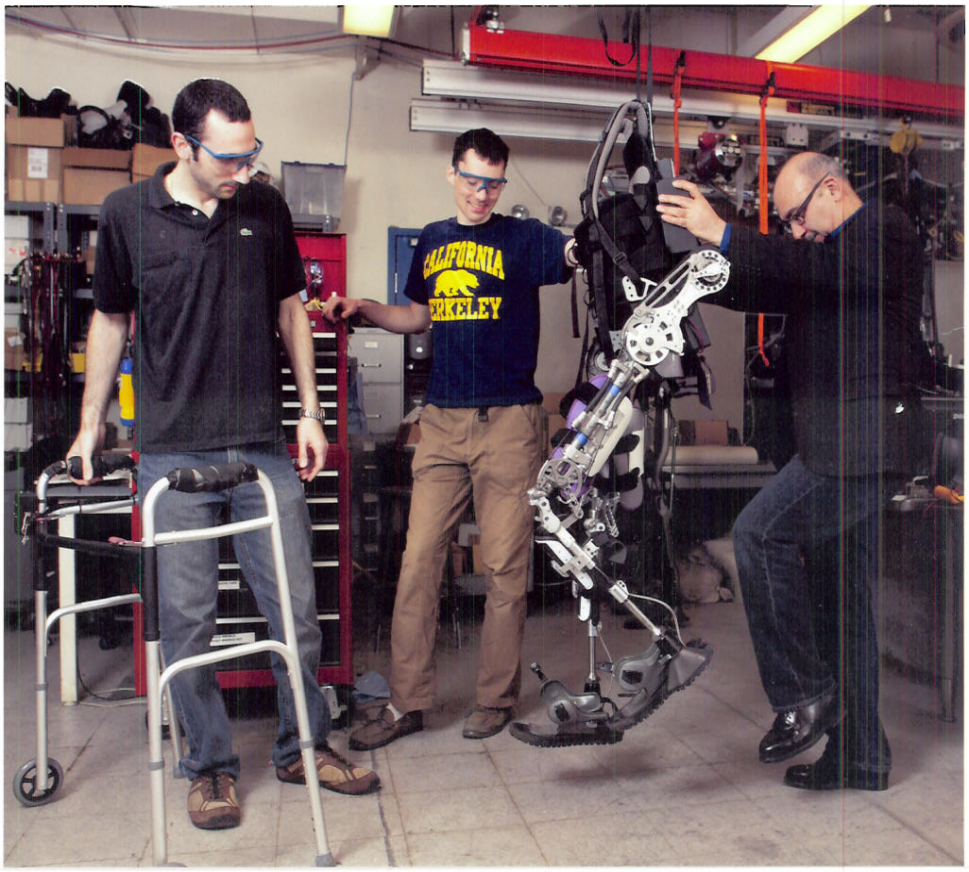
To build an inexpensive yet reliable product, the engineers are taking an unconventional approach: less-is-more. "As an engineer, always adding is easier than subtracting," says Kazerooni. Students are often taught to add extra electronics, aluminum or sensors to ensure the integrity of their projects. Austin is different. "My philosophy is to take out while keeping the performance; our aggressive cost targets dictate moving functionality from standard engineering to innovative designs and intelligent computation," Kazerooni says.

Achieving that simplicity is actually very challenging because an exoskeleton like Austin is inherently complex. It works through a delicate interplay of mechanical hardware, electronics, computer software and human-machine interface.

While Austin remains a project in the works, the engineers say they have devised a number of creative responses to engineering challenges. The machine has been programmed, for instance, to work off a basic $20 or $40 computer rather than a more sophisticated $600 model. Instead of relying on actuators and other fancy electronics, the engineers made innovative use of hardware in the leg mechanism to produce a walking gait. Austin has a minimal number of sensors. To further cut costs and complexity, the metal hip and knee mechanisms on each leg are coupled and operate with a single motor.

The student researchers juggle work on the project with the demands of school, says Michael McKinley, a 23-year-old mechanical engineering doctoral student working on Austin's mechanical design and hardware system. "It comes down to cleverness. We're trying to design a device that does as much as possible with as little hardware as possible." Beyond reducing costs, a simpler design means less risk of system failures, the researchers say.





"IT COMES DOWN TO CLEVERNESS": In designing the Austin exoskeleton (next page, right), the team tries to use as little hardware as possible. The process entails adjustments to the design (above), a series of discussions among team members (right) and testing by Whitney (next page, left).

OPERATING INSTRUCTIONS

To operate the machine, a user or "pilot" like Whitney sits in a wheelchair and fastens himself into the exoskeleton with straps and clips at his shins, legs and midsection. He activates the machine wirelessly with a switch in either a walker or crutches. Each operation—standing, walking, stopping or sitting—is initiated by the computer, which in turn sends a signal to motors and gears. Whitney shifts his weight to help guide the machine through its maneuvers.

Whitney's pace is still slow and somewhat mechanical. But the researchers are optimistic they will achieve a brisker, more natural gait. They also predict that their finished product will be much lighter than Austin's current 50-pound weight.

To ensure his safety, Whitney often walks inside the lab with a tether linked to a ceiling-mounted beam. He must use a walker or crutches and is spotted by one or more of the graduate researchers when he leaves the lab.

"This device must be such that even if the wearer tries to fall, he can't," says Kazerooni. To that end, the machine's knees were redesigned this winter to ensure that they reliably locked whenever Whitney's legs shifted from a step to touching the ground.

The Austin project experiences ups and downs typical of most scientific research. There are constant modifications as the team spots problems and devises fixes. "We're moving forward," says Kazerooni, whose lab is already working on a next-generation prototype that could be worn under clothing.

Whitney is an integral part of the lab's effort. Only slightly younger than the graduate students themselves, he has put a human face on the project. He also has become both a colleague and a friend.

Whitney heard about the project from an acquaintance last summer. He signed on as a test subject soon afterward. "I'd been in a wheelchair three years when Professor Kaz said he wanted to get me walking again. The question isn't 'Why would I [want to get involved]?' The question is 'Why wouldn't I?'" Whitney recalls.

Whitney comes to the lab two or three times a week to test the device, providing an invaluable user's perspective. Without Whitney, "everything is kind of theoretical," says Jason Reid, a 27-year-old doctoral student in charge of Austin's control system. "All that theory doesn't mean anything until someone starts using the machine."

During their long hours in the lab, Whitney and the student researchers chat and listen to rock music. Their commitment to the mission is shared and deep. "I think we all live this project," says McKinley. "I know we all dream about solutions to problems."

Whitney's first steps in January were unforgettable. "He painted a picture for us far more beautiful than we thought," Kazerooni says.

Since that day, Whitney says he's become a changed person. "It taught me how careful you want to be with the word 'impossible.'"

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