"THE BIONIC BODY"
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ALAN ALDA Jim Jatich is telling his hand to grip, using a computer and wire electrodes that are implanted under the skin. On this edition of Scientific American Frontiers - re-engineering the human body.

ALAN ALDA (NARRATION) We'll see the first big breakthroughs in repairing injured spinal cords. We'll tap into brainwaves, to control machines and computers. We'll bring damaged limbs back to life. And I'll have a conversation with Christopher Reeve -- about the reasons to hope.

CHRISTOPHER REEVE You know that pigs aren't going to fly, but I might walk!

ALAN ALDA I'm Alan Alda. Join me now for The Bionic Body.

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SHOW INTRO

ALAN ALDA In this program we're going to look at a challenge that, just a few years ago, most scientists would have said was simply beyond our reach. The challenge is to repair broken or damaged nerves, particularly in people who have suffered a disabling accident which has left them paralyzed. There is now real progress being made in stimulating nerves to repair themselves, although it's still at the lab level and a long way from being applied to people. Then we're going to look at a different kind of approach to the same problem. This is a true marriage of biology and technology in which actual hardware is being implanted in the body to restore functions that no longer work. Nerves are being replaced with computers and wires. So there's some terrific science going on in these areas, but we're not going to lose sight of the fact that this is all for one thing - to help

the people who need it. Later on in the program I'm going to be talking with Christopher Reeve who, since his accident, has become an important advocate on behalf of disabled patients. But first we're putting on our white coats, and heading into the laboratory.

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BORN AGAIN NERVES

ALAN ALDA (NARRATION) And in the laboratory we find - laboratory rats. But what a rat - this one had a crippling spinal cord injury, and it's literally back on its feet. This story is about how that was done. I'm with John McDonald, a neurology professor at Washington University in St. Louis.

JOHN MCDONALD What we're going to look at is an actual transplantation procedure, where we're gonna take the embryonic stem cells that have been instructed to become nervous tissue and we're gonna put those into the middle of the damaged spinal cord of a rat.

ALAN ALDA (NARRATION) Repairing damaged nerves is one of the possibilities opened up by an exciting new area of research using embryonic stem cells.

ALAN ALDA You have stem cells in here?

JOHN MCDONALD Yes. Let me show you how we grow the step cells. What we're looking a here, if you look closely, you can see small clusters of hundreds of cells. In fact, each one of those very closely resembles the early embryo after fertilization.

ALAN ALDA (NARRATION) The cells have not yet started to differentiate into everything that goes to make, in this case, a mouse - like bones, muscles, or nerves.

ALAN ALDA What kind of stuff tells them to become nervous tissue and how does it work? I don't get… that's an amazing idea. What kind of stuff is it?

JOHN MCDONALD It's very interesting. In the early embryo the switches, the major switches are very simple things. And the expression of a chemical called retinoic acid is all that it takes to tell these cells to become nervous tissues.

ALAN ALDA And you synthesize that? You can make retinoic acid as much as you want?

JOHN MCDONALD Exactly.

ALAN ALDA And you just squirt it around on that stuff and they start to turn into nervous tissue?

JOHN MCDONALD Yes.

ALAN ALDA (NARRATION) The embryos are treated with retinoic acid for four days, then an inhibiting chemical is used to stop them from developing further, while they multiply.

JOHN MCDONALD If we begin the week with one of these flasks, we end the week with 256. So there's really an unlimited supply. The cells divide almost every 14 hours. So let's take a look at these.

ALAN ALDA (NARRATION) At this stage they're called neural precursor cells - they're ready to make any of the three kinds of nerve cells, but while the inhibiting chemical is present, they just multiply as precursors.

JOHN MCDONALD So what we're seeing here are one individual cell that's now just finishing division. The two dark areas are the DNA. And the cell will cleave across here.

ALAN ALDA (NARRATION) A single transplant needs a couple of million cells, so there's a continuous precursor cell production line running in the lab. Then when the inhibiting chemical is removed, the nerve cells themselves grow. These are neurons, with their connecting axons.

JOHN MCDONALD What we're looking at here is a culture dish filled with cells that have now become neurons. You can see the little round circle is a neuron, a cell body.

ALAN ALDA And that coming out of it, is that an axon?

JOHN MCDONALD This is the axon. There are millions and millions of the axons and connections -- those same ones that need to be repaired.

ALAN ALDA (NARRATION) Here's another kind of nerve cell, called an oligodendrocite. Its job is to wrap the axons with insulation.

JOHN MCDONALD What's showing here in green is a single oligodendrocite in the culture. And these are all the branches. And you can see that this oligodendrocite reaches out and wraps only one part of that axon and then it

continues, unwrapped. Here's another connection that's wrapped multiple times in multiple segments.

ALAN ALDA So this one oligodendrocite is wrapping many different axons or connections.

JOHN MCDONALD That's right. Typically in the spinal cord an oligodendrocite will wrap up to 15 different axons, or connections between cells.

ALAN ALDA (NARRATION) Here's an axon wrapped with its new layers of insulation - like a plastic cover on a copper wire. Damaging the insulation is an important type of spinal cord injury in people, as with this injured cord of a lab animal. The cord is not severed, but there's a serious loss of function, mainly because existing axons have lost their insulation. By transplanting about 2 million nerve precursor cells into the injury, an astonishing recovery of function has been achieved. The researchers think the animal's body signaled the transplanted cells to make oligodendrocites, which re-wrapped the exposed axons with the insulation - called myelin - that they need to work again.

ALAN ALDA So nerves that don't work any more simply because they've lost their myelin, you can get them to work again.

JOHN MCDONALD Right. If we can just simply replace that then we can get important recovery of function, such as recovery of bowl and bladder control or improved movement of a hand. Now to you and I that might not sound like a lot…

ALAN ALDA Oh, it's gigantic if you're missing that…

JOHN MCDONALD Exactly. The gains in the level of independence for a person to be able to control their own bowl and bladder function, or allow them to use a hand, are the difference between living in an institution and living at home.

ALAN ALDA You know, if I was trying to figure out how to do this I'd say, well get some cells and stick them in there. You know, get some fully grown cells and stick them in. You, you put them in at the right stage so they'll respond to signals and actually grow on their own, and grow into the necessary kinds of cells.

JOHN MCDONALD Yeah, I think we've taken advantage of power of development and said, jeez, you know, we don't know the myriad of signals. Let's put them in at an early stage where we can just throw a few switches, and get them going and let the body and the nervous system do the rest.

ALAN ALDA (NARRATION) Re-myelination of existing axons using stem cell transplants is a tremendous breakthrough. But for a complete cure, new axons need to grow as well, so as to reconnect severed nerves.

ALAN ALDA How do they know where to go? How do they know where to grow to? Why don't they just grow in every direction?

JOHN MCDONALD That's the most difficult question now. It's interesting that if you put in cells, they'll tend to migrate towards the injury site because the injury site gives signals to get them to go there. The most difficult thing right now is to get these neurons to make the appropriate connections over long distances. That has not been achieved yet.

ALAN ALDA (NARRATION) Several hundred thousand Americans could benefit from spinal cord therapy, and the pace of research is quickening. Encouraged by Christopher Reeve, eight centers around the world have formed a consortium, to swap ideas and results. Everyone is feeling optimistic, but here at the University of Miami, a consortium member, Mary Bunge doesn't underestimate the challenges ahead.

MARY BUNGE There are many different types of nerve cells. There are millions of fibers in the spinal cord. They are travelling in two different directions. They are ending in different areas of the spinal cord. It's a very complex problem.

ALAN ALDA (NARRATION) Here they're developing a completely different transplant approach - using not stem cells, but what are called Schwann cells from peripheral nerves, the ones found in arms and legs. Unlike spinal cords, peripheral nerves can repair themselves. The Schwann cells are cultured, and then soaked up into little plastic fiber cylinders. The cylinders are used to take on the biggest challenge of all - to make a living bridge between completely severed parts of a spinal cord. A section of cylinder, containing about six million Schwann cells, is placed across the gap, in this lab animal test. The extraordinary result is that new axons - nerve fibers - are attracted to grow into the bridge. There the transplanted Schwann cells wrap the new axons with the vital myelin. Once again, the body has been coaxed into doing its own thing. The Schwann cells manage to give the right signals for new axons to grow, and then make new myelin as well - even though repair doesn't normally happen in the spinal cord.

MARY BUNGE What has happened here is that the fibers grew into the bridge and then the Schwann cells that had been transplanted there then formed myelin around the axon. This is the outline of the Schwann cell here. Here is its nucleus. The Schwann cell became related to this axon. The myelin sheath appears as a dark ring.

ALAN ALDA (NARRATION) They can get new nerves to grow into the bridge, but not out again.

MARY BUNGE A challenge now is to improve the amount of growth of axons from the bridge into the cord.

ALAN ALDA (NARRATION) The latest approach is to take cells from the nose - the nose of a lab animal, again. In all mammals the nose constantly renews its nerve connections to the brain. So, the nose cells are injected into the spinal cord, close to the bridge. The hope is that the nose nerve cells will somehow attract the new nerves out of the bridge, so they can make new connections in the spinal cord. And that's in part what the nose cells did, with new axons showing up an inch away from each end of the bridge. But right now we don't know if there were new connections, and disappointingly there was no significant improvement in the experimental animals' function. So what does this all add up to for people? There's no doubt that practical treatments for injured spinal cords are still years away. But at the same time you won't find a scientist in the field who'll say we're not going to win this battle before long.
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I MIGHT WALK!

ALAN ALDA (NARRATION) I've come to see Christopher Reeve, at his house not far from New York City.

CHRISTOPHER REEVE It used to be woods.

ALAN ALDA (NARRATION) Chris is now a quadriplegic, confined to a wheel chair. He breathes with the aid of a ventilator. In 1995, Chris suffered a severe fall from his horse during a competitive jumping event in Culpeper, Virginia. With an injury at what's called the C-2 level, he lost control of his body below the neck.

CHRISTOPHER REEVE I was injured at the second vertebrae level, but my spinal cord was not cut. What happened was I had a hemorrhage right in the middle of the cord at C-2. And then it caused atrophy. So right at C-2 the cord is one quarter its normal size. So think of it as a kinked garden hose.

ALAN ALDA (NARRATION) Chris Reeve, seen here with his wife, Dana, and son, Will, prepared for a lifetime of paralysis. But soon he was to discover that for the first time, there was hope that science could tackle spinal cord injuries.

ALAN ALDA Were you encouraged to have this kind of hope when you first had the accident, when you, say, were in rehab? Or were you encouraged to accept and adjust to …

CHRISTOPHER REEVE No, I was encouraged to accept and adjust. And in fact, I remember one researcher saying that ah, "Well, in the beginning, one always hopes, but over time, hope ebbs." You know, and this is a researcher who now is at the forefront of the solution to the problem. Now we're at a stage where leaders in the field have discovered that exercise is absolutely essential.

ALAN ALDA Now, for what? Exercise is essential to get you ready for the time when your nerves may be able to be regenerated? Or just in general?

CHRISTOPHER REEVE Well, there's of course just immediate benefit, in that you avoid infections, antibiotics, etc. And the other is, think of it as the transcontinental railroad. The patient starts on the east coast by doing his exercise and improving and heading west, while the scientists start from the west, and go from the Petrie dish to the monkey or the rat and then into the human, and hopefully they meet in the same place, in Utah or wherever.

ALAN ALDA (NARRATION) Chris exercises 3 to 4 hours a day, using specialized equipment. Equipment he wants insurance to provide for all patients, by the way. There's a bicycle used in conjunction with electrical muscle stimulation, and a table that tilts upright.

CHRISTOPHER REEVE We loosen the straps and somebody stands in front of me so that I don't fall over, but actually I have good equilibrium, and what we do is I mentally think -- lean to the right and my body does it, and then I mentally think lean to the left and I go left and put all my weight on my left foot. And that is something where the brain is telling the cord to shift weight.

ALAN ALDA (NARRATION) Work on a treadmill is intended to stimulate the spinal cord's own memory of walking patterns - we'll have a story about this idea later on. Over all, the point is to use to the full the few remaining spinal connections, so he's ready to meet the scientists when they get to Utah. One short-term goal is simply to breathe naturally. He can already do this half and hour at a time.

CHRISTOPHER REEVE What I'm trying to do is get off the vent and I do that with certain breathing exercises but also the treadmill therapy is helping that

ALAN ALDA What is the connection? How does that help? Well, you're activating the cord. You're taking advantage...

ALAN ALDA So you're taking advantage of kind of an automatic breathing response?

CHRISTOPHER REEVE Of what's left. I'm not yet able to breathe automatically.

ALAN ALDA Is your diaphragm working?

CHRISTOPHER REEVE My diaphragm works, which is really a miracle, because I'm injured at a level way above the diaphragm but, by exercising very hard over the last five years I've improved, so I'm going up rather than down. Psychologically and emotionally that makes a tremendous difference.

ALAN ALDA Oh I can imagine. You know, there's this old saying -- give me the strength to do something about what I can do something about and to accept what I can't do anything about, and the wisdom to know the difference. Your recent life has been kind of a vivid example of how hard it is to strike that balance, to find that wisdom. How do you do it? I mean, you must have to accept a certain amount.

CHRISTOPHER REEVE I don't buy into it at all.

ALAN ALDA You don't accept any of it?

CHRISTOPHER REEVE No. What I say is, Who knows what the horizon is?

ALAN ALDA Yeah.

CHRISTOPHER REEVE You know, who knows how far we're going to go, why should we put limits on it? You know that pigs aren't going to fly, but I might walk, you know!

ALAN ALDA (NARRATION) Chris Reeves' accident compromised a highly successful acting career. He decided that he should use his celebrity for all it was worth, to further the cause of research into spinal cord treatments.

CHRISTOPHER REEVE The main idea is to put a vision out there, and then I even went so far as to do a commercial last year.

ALAN ALDA I didn't see the commercial.

CHRISTOPHER REEVE Well, what happens in the commercial is that I'm seen walking, to give a prize to a scientist who, some time in the future, had cured spinal cord injuries. And it was very upsetting to some people, very uplifting to others but, five months after the commercial was on the air, people are still

talking about it. You want that debate, you want that controversy, you want people to be agitated, but I checked with all the major scientists in the country that I, you know, have a relationship with and they said, No, there's no reason not to put that vision before the public, because it will happen.

[INSERT LOCAL ENHANCEMENT HERE]

TV COMMERCIAL And in the years since the new millennium, the world has seen such progress. In 2004, the tide was turned against AIDS, two years later, great strides against cancer, and tonight…tonight we celebrate a remarkable breakthrough in spinal cord injuries made possible by countless researchers and contributors. And to present this award, we have some very special guests. In the future, so many amazing things will happen in the world. What amazing things can you make happen?

ALAN ALDA What do you think your main contribution is? Is it raising money? Is it focusing attention? Being the person who gets everybody in the boat to row together? What do you think, what do you think of as your main contribution?

CHRISTOPHER REEVE Well, my responsibility is all of the above. You know, I'm president of a club I didn't want to join, but ah, nevertheless I have to take some responsibility. Not to do so would be really immoral. And I have the chance to speak up for a lot of people, you know, who could never get to a congressman or never testify before a Senate committee or influence a budget. So I actually, er -- I can't say it's my favorite thing to do, but nevertheless, er, psychologically, emotionally it really helps me that, you know, I can be of some use.

ALAN ALDA (NARRATION) And when he does get back to work, he's still trying to be of some use. In this remake of the Hitchcock classic, Rear Window, he wanted to help change the widespread stereotype of disabled people, as isolated and embittered, to something different -- to an image of people who could be, in fact... of some use.

CHRISTOPHER REEVE (IN CHARACTER) Achilles, bring up telephone, dial 911.

OPERATOR 911 Operator.

CHRISTOPHER REEVE I need to report a domestic altercation.

OPERATOR Can you describe what's happening, sir?

ALAN ALDA (NARRATION) Christopher Reeve could hardly get much further from the stereotype. He set up a foundation which helps fund and coordinate the

world's best research in spinal cord injury, and he's a tireless advocate. What was an immensely creative life before the accident only seems to have become more so since, in both public and private life.

CHRISTOPHER REEVE You find alternate ways to accomplish and to express your needs, your desires, etc. For example, I taught, when I was on my feet, my big kids how to ride a bike, taking the training wheels off. But my young son, Will, was a little afraid to take the training wheels off. But I actually sat out in our driveway in a wheelchair. Somebody took the training wheels off and I talked him through how to do it. Now, isn't that cool? Who would have thought?

ALAN ALDA That's great. You're relentless. I mean, you really don't give up.

CHRISTOPHER REEVE No, because now we had a new way to connect. And so many ways of connecting have been taken away, you know I haven't been able to give him a hug since he was two years old, and he's almost eight. But he's got to hear it through my voice and through my eyes. And just from being there. So I have to find ways to give him what he needs, and one of my jobs -- and this is the paradox of having a debilitating injury or disease -- is that you have to find a way to be more generous than you ever were before, when you were on your feet. And what I mean by that is that you have to set people free so they don't spend their life worrying about you.

ALAN ALDA Do you think about, do you let yourself think about how long it will take before they'll be able to get to the point where you can walk again?

CHRISTOPHER REEVE No I don't, er, I don't measure it in terms of month, days, or years. I measure it in terms of how hard people are working. So sometimes if I see a scientist at too many dinners or, you know, out at too many meetings I say, Go back to the lab, get out of here. Go put the white coat on, get to work. So I have a reputation as sort of an amiable pest.

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MOVING MEMORIES

ALAN ALDA (NARRATION) We're back at the University of Miami, to look at a remarkable study that's just getting under way. Rudolfo Stecco has been partially paralyzed since a car accident two years ago. He's one of 200 patients who, over the next 5 years, will test the effects of intensive exercise - but exercise during which only about 1/3 of the body's weight has to be supported by the legs.

BLAIR CALANCIE 88?

ALAN ALDA (NARRATION) There's a fascinating story behind this study. It all began 6 years ago with a patient who was exercising hard in an attempt to improve his walking, which was very limited. Blair Calancie, the study director, takes up the story.

BLAIR CALANCIE He could walk about 75 feet in one 45 minute session. Clearly it was non-functional in such small distances. The fourth year he'd come down he decided he was going to go all out. He was going to embark on a very strenuous physical conditioning program under his own direction, and worked out for four hours on the Monday, four hours on the Tuesday, standing, exercising, a lot of strenuous work. On Wednesday he comes in and says to one of our therapists, I'm getting these weird spasms when I lie down, it's like I'm walking. She then responded as was her way, You're a spinal cord injury, you have spasticity, get used to it!

ALAN ALDA (NARRATION) Fortunately, Blair Calancie decided to take a look for himself anyway, and what he found was a completely unknown phenomenon.

BLAIR CALANCIE Just as he had described to us, the moment we took him from his wheelchair and he laid out, flat on his back, his legs began an involuntary stepping pattern. What was intriguing was, and what really set us out on this whole area of research, is that at the same time the involuntary stepping started at night, his ability to walk in the day time, volitionally, improved by an order of ten. So he went within a week from walking 75 feet in a session, to five and six and seven hundred feet in one session .

ALAN ALDA (NARRATION) Conventional therapy after a spinal cord injury is something like this - mild stretching and gentle movement. But suddenly, here was the possibility that intensive exercise would dramatically improve walking, even 17 years after the injury in this case.

BLAIR CALANCIE An important consideration for this study is that everybody has to be at least one year post injury. And under today's current approach of managed care it's not at all unusual for an individual with an acute -- they've just had a recent spinal cord injury -- to be discharged from hospital at six weeks, seven weeks, eight weeks. Maybe they'll get rehab for another month to six weeks after that and beyond that, it's over.

ALAN ALDA (NARRATION) Ida Fisher, for example, has been partially paralyzed for 4 years..

BLAIR CALANCIE Ready to fire up? Let's go.

ALAN ALDA (NARRATION) She's testing the treadmill, and like all the subjects she's partially suspended -- she'd barely be able to move at all otherwise. Christopher Reeve does his treadmill workout regularly, by the way. After 6 weeks in the study, Ida's seen a dramatic improvement.

IDA FISHER Before I walk fast, I walk only half an hour. Now I walk an hour.

ALAN ALDA (NARRATION) The study is recording many such improvements. The intriguing possibility is that the spinal column itself contains some of the instructions for walking. This Central Pattern Generator, as it's called, is known in animals - but has never been seen before in humans. Hard exercise - only possible with these subjects when partially suspended -- somehow re-stimulates the Central Pattern Generator.

BLAIR CALANCIE We're seeing dramatic improvements in individuals who are at least one year post injury, in often cases five, six, ten years post injury, which suggests that there's a great deal of untapped potential in these individuals. It's a very strong argument to the managed care companies, to physicians, that the common phrase of, Whatever you have in one-year post injury is what you've got for the rest of your life, needs to be rethought.

ALAN ALDA (NARRATION) And, it's an unexpected new source of hope for people with spinal cord injuries.

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NERVES OF STEEL

ALAN ALDA (NARRATION) Don Crago is paralyzed from the waist down. But using artificial electrical muscle stimulation, he can walk. Dr. Byron Marsolais started this project.

DR. BYRON MARSOLAIS He has absolutely no control of his legs at all. He is totally and completely paralyzed, and every bit of motion that happens is coming through the electrical stim.

ALAN ALDA Don , do you get all your balance from holding on to this walker?

DON CRAGO Yes, I do. Yes, I do.

ALAN ALDA Does that put a lot of pressure on your arms?

DON CRAGO Not really. Most of the pressure's on my legs. Actually, I prefer to let my legs do the work, 'cause if I did it with my arms, I would be tired out.

ALAN ALDA Yeah. How tiring is it to take it every step?

DON CRAGO Not too bad. It's comfortable, you know? But after the end of the walk, I will breathe heavy.

ALAN ALDA Standing takes a lot of energy because you have to stimulate the muscles for a prolonged period?

DR. BYRON MARSOLAIS Right. He is standing by stimulating the flexors and the extensors --the antagonistic muscles -- all at the same time. So he's stiff as a board..

ALAN ALDA And that charge just has to be constant...

DR. BYRON MARSOLAIS It's constant...

ALAN ALDA If you let up on it, he's liable to tip one way or another.

DR. BYRON MARSOLAIS Oh, he would, for sure. And so he looks good standing tall and stiff...

ALAN ALDA But you feel the strain?

DR. BYRON MARSOLAIS But he's got strain.

DON CRAGO Yeah, I feel a strain.

ALAN ALDA (NARRATION) My introduction to the Functional Electrical Stimulation, or FES, program, was 8 years ago.

DR. BYRON MARSOLAIS Now what I'm trying to get to is his gluteus maximus muscle, the big seat muscle.

ALAN ALDA (NARRATION) Dr. Marsolais showed me how he implants wire electrodes.

ALAN ALDA What you're inserting into the muscle, that's not the electrode itself.

DR. BYRON MARSOLAIS No, no, this is just a little probe, a very tiny probe.

ALAN ALDA And the reason you're doing this is to see if you can get the muscle to react, to give it's greatest response?

DR. BYRON MARSOLAIS Exactly. And I want just the right muscle. That's the muscle that we want, it goes right down here into the femur, which is the big leg bone. And you see how it's beginning to jump there? It's starting to do what we want. I think I can do better. And in order to do better I have to get it right beside the nerve.

ALAN ALDA (NARRATION) Dan Kemp, paralyzed in a car accident is on the table.

ALAN ALDA Now I think Dr. Marsolais looks like he's found the spot here.

DR. BYRON MARSOLAIS That looks pretty good here, yup. That's getting a pretty good, tight...

ALAN ALDA I can see it.

DR. BYRON MARSOLAIS See how that jerks thing together there.

ALAN ALDA It looks like about an inch-and-a-half from where you were first searching for it.

DR. BYRON MARSOLAIS Yes, that's right, although we're angled a bit down. We started about here and now we're about here, so we were a good inch away.

ALAN ALDA (NARRATION) Once he's found the best stimulation point for the muscle, a hair-thin permanent wire implant is slid into place. Dan was one of many experimental subjects who volunteered for the program. In his case he received 8 electrodes in each leg.

DR. BYRON MARSOLAIS Now we just bring this down to exactly the position that we were before.

ALAN ALDA (NARRATION) The patients, and Dr. Marsolais, were literally stepping into the unknown.

ALAN ALDA How do you feel when you are going through this? Do you feel a little like a guinea pig? DAN KEMP Yeah I do, but it's well worth it. You know, down the road, people will be able to look back and say if it wasn't for people like me that they wouldn't have gotten as far as they've got in the new procedures. So you know it goes down the line. Everybody helps everybody else, whether they realize it or not.

ALAN ALDA (NARRATION) Eric Bellamy, paralyzed in a motorbike accident, agreed with Dan that it was worth being a guinea pig. He saw simple, basic ambitions for himself, and for the program.

ERIC BELLAMY I see being in a chair always, but I see being able to go up steps and knock on a friend's door and say, Hey, I'm down here. Instead of running around the house and screaming, Hey I'm here, I'm here. I see being in a convenience store -- one step, you know. Being able to get up and go through a narrow door to go get into the bathroom -- just for them answers. And if they can come up with that right there. Your life's in a chair, but being able to overcome difficulties would be a tremendous step. And that's what we're working on right now.

ALAN ALDA (NARRATION) Eric was one of 5 volunteers who received the most complex of the experimental systems, with a total of 40 implanted, and 8 external electrodes. The computerized control box could handle 48 electrodes simultaneously, with connections made through the skin on his thigh. One big goal was to establish how many muscles needed to be stimulated for effective standing and walking. Working out how to sequence the firing of the electrodes was another challenge.

PAUL MILLER OK, go ahead and stand up.

ALAN ALDA (NARRATION) In this trial, 20 muscles per leg were being stimulated, compared to the 50 per side that are involved in natural walking. Eric was able to walk relatively smoothly, although he still needed to use his arms to balance. Developing an artificial balance mechanism is still one of the goals, but they have been able to reduce the number of muscles needed for walking to only 8 per side - as in the latest system we saw Don Crago using earlier. But Eric's muscles also had to work constantly at full blast.

PAUL MILLER They're using tremendous amounts of muscle mass. Their quadriceps are on 100%. Their gluteus muscles are on 100%, their hamstring muscles are on 100%. Their back muscles, everything's just blasted.

ERIC BELLAMY Whenever they do something, their using 100% of all their strength. Whether it's one step, two steps, they're using everything they got. Letting me stand, everything goes right into it. 100%, bam!

PAUL MILLER OK?

ALAN ALDA (NARRATION) With tough, motivated subjects like Eric, they were eventually able to work out how to reduce the high levels of muscle stimulation,

and they also figured out the best design philosophy. It's that simpler is better -- they realized that even the most complex systems were going to get tripped up by the real world sometimes. Better instead to go for simpler, standard systems that can bring basic benefits to the largest number of people, quickly. Many of the pioneers in FES research have now dropped out. Eric got a bad infection. Dan couldn't keep up the long commutes to the hospital. But today, many people with spinal cord injuries have good reason to be thankful for the pioneers' efforts.

JEN PENKO This is an easy introduction to the real world, I guess you could say.

ALAN ALDA (NARRATION) Jen Penco is one of the beneficiaries. She's showing me a rehab area at Cleveland Metro Medical Center - the first of 3 centers around the country to be working with the simplified, standard systems.

JEN PENKO For instance there's curb cuts and those types of things.

ALAN ALDA It takes a little extra energy to get up that, doesn't it?

JEN PENKO A little bit, but you'll get curbs in the real world that are a lot more difficult than that.

ALAN ALDA Yeah.

JEN PENKO You can just set it right there, because I'll get myself set up.

ALAN ALDA (NARRATION) Jen has a simplified system that just does one thing - allows her to stand.

JEN PENKO So the light by the "stand" means that it's ready to stand and all I need to do is press this button to go, and it'll stand. Ready?

ALAN ALDA Yeah.

JEN PENKO Are you sure you're ready?

ALAN ALDA Yeah, yeah. I'm ready, I'm ready.

ALAN ALDA (NARRATION) Jen's system has only 4 implanted electrodes per side, but that allows her to stand and get around just enough to really make a difference.

JEN PENKO So here I can reach up, grab window cleaner and hand it over to you.

ALAN ALDA How long can you stand before you start to feel stressed out or you're breathing heavily?

JEN PENKO We did a test on that. 33 minutes and 8 seconds was my time figure right now. And that was a few weeks ago, so. Usually when you're in a grocery store, one of the tough things, when you're in a wheelchair, is you can't really see within these big bins. So that way you can reach over, pick up some Weight Watchers, good lord knows I need it. And you can start to see things from a standing level that you really can't see from a sitting level. Whereas if I was at a sitting level I'd be lucky if I'd be able to see what was actually in there.

ALAN ALDA Do you want to go to walking? Is that something you have in mind?

JEN PENKO Absolutely. Absolutely. To be able to ambulate is fantastic. I mean, just to be able to stand. We're focusing on the functional things, but there's a lot of health benefits to standing as well. I mean, people that are in wheelchairs that don't stand, you have problems with the shortening of muscles, with osteoporosis, with circulation,

ALAN ALDA So you have to be able to get into pretty much any kind of a seat…

ALAN ALDA (NARRATION) Simply transferring from one seat to another is a big benefit.

ALAN ALDA ...automobile seat, and a booth like this which is different from a chair. One, two three. Those are three slow seconds.

JEN PENKO They are. And considering I'm from the Boston area, I've had to learn how to count a lot slower than out here. So it took me a long time to learn how to count.

ALAN ALDA They count slower in Cleveland?

JEN PENKO I guess they do.

ALAN ALDA (NARRATION) Another part of the design philosophy is modularity. If Jen and her doctors decide everything is working well, she can get another 8 electrode implants, which will allow her to walk. JEN Now I'll sit.

ALAN ALDA So you have the same three seconds before it puts you in the seated position?

JEN PENKO Uhuh. Same audio that it goes through as well. Same beeping cycle.

ALAN ALDA Yeah.

JEN PENKO So it's just like a habit. Training me like a mouse. There you go -- beep. Three seconds later -- beep. And I'm standing up.

ALAN ALDA What do you call the thing that's implanted. What is that? JEN It's my receiver.

ALAN ALDA How big is it?

JEN PENKO Um, it's about that big. It's not very big at all. In fact...

ALAN ALDA (NARRATION) A big change with the standard systems is that no wires pass through the skin.

JEN PENKO So this is the box that hold the batteries, that holds the software and circuit boards.

ALAN ALDA (NARRATION) Instead there's a transmitting coil with an implanted receiver.

JEN PENKO I have it taped onto the skin so it won't move. So I have this coil that sends the radio waves to the receiver that's right here, and you see the little bump in the skin right there? That's the receiver.

ALAN ALDA (NARRATION) There are now nearly 200 standard systems in use, but research is continuing. Jim Jatich received the very first implanted electrodes, in 1986, to allow his left hand to grip.

JIM JATICH Since I had this implant, once it's put on me in the morning, I'm on my own and I can write for myself, feed myself, answer the phone, take messages, work on a computer. I do engineering drawings on the computer, I'm trying to start my own business doing that.

ALAN ALDA That would have been out of the question, I mean without a tremendous amount of help.

ALAN ALDA (NARRATION) Jim lives with his family just outside Cleveland. When we first met him in 1993, he described for us how he had been injured.

JIM JATICH Back in the summer of 1977 I was swimming with several other friends in a lake nearby. They dove into the lake and started swimming away. I was the last one to dive into the lake. I hit something on the bottom. It wasn't

anything hard that knocked me out. But I felt my neck jam into my shoulders, and then I slowly started sinking into the seaweed at the bottom of the lake. I couldn't move anything, my arms or legs, when I felt two arms on my shoulders and they pulled me to shore, and right away I knew that I had broken my neck.

ALAN ALDA (NARRATION) Jim has no lower body control, and only limited upper body strength. For 23 years he's allowed the researchers to try out new FES systems on him. In 1993, for example, they were perfecting a joy stick controller for the 8 electrodes that give him his hand grip. The joy stick was attached to his right shoulder. So a quick shrug of the shoulder activates the grip. And then a double shrug relaxes it. Jim was also one of the first to try an implanted receiver, so no wires penetrate the skin.

JIM JATICH What we have is like a joy stick implanted in the bones of my wrist.

ALAN ALDA (NARRATION) Today Jim is trying another experimental control system.

JIM JATICH There's a magnet and a sensor, and as the wrist bones pass each other that sends a signal to the implant, and depending at what angle I'm at, whatever is programmed into the computer on the back of my wheel chair, that's how much strength and how fast my hand closes.

ALAN ALDA So the magnet and the sensor, depending on how far apart they are, as you move your hand back, that regulates everything that's gonna happen.

JIM JATICH Right

ALAN ALDA (NARRATION) Jim and the researchers have been working with the implanted magnet control for a couple of years.

ALAN ALDA Now if that were full of coffee and heavy…

JIM JATICH You can see how strong I'm holding it.

ALAN ALDA Yeah, you have a really good grip on that.

JIM JATICH Yeah.

ALAN ALDA Yeah. You're a good actor, too. Looked like you had something in there.

JIM JATICH Oh, it's hot!

ALAN ALDA (NARRATION) With the magnets controlling his left hand, Jim's joy stick can now control a new implant system in his right hand, so next he'll be working with the researchers on tasks that need two hands simultaneously. Jim's essentially a member of the research team - but one perhaps with a special perspective on the benefits of the FES program .

JIM JATICH You know I've talked to friends of mine that are paralyzed. They won't go into restaurants when we have meetings, you know like a support group meeting, because they can't feed themselves. They don't want to see anyone feeding them so whenever we have meetings in a hospital or something they show up, but when we have it in a restaurant they won't go, because someone has to feed them, you know.

ALAN ALDA So there's a series of things that don't get done, because of a simple thing like being able to pick up a fork. I mean, you get less social.

JIM JATICH That's right. An example is a girl that came into this project to get an implant. When she first came in, her face was down, she wouldn't talk to anyone, no eye contact. After she got the implant she's feeding herself, going out to restaurants, she enrolled back in school. Now she's an advocate, talking to everyone about it. She started a support group. And I mean, you know it just changes people's lives. And that's the kick I get out of it, to see how people change.

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MIND OVER MATTER

TECHNICIAN How's that feel, OK?

ALAN ALDA Yeah, that's very nice.

TECHNICIAN Not too tight?

ALAN ALDA No, no, no. I like this.

ALAN ALDA (NARRATION) The producers have made me wear these attractive hats before, but it's usually in a good cause. And in this case I was presented with a really fascinating challenge. I'm trying to just think about moving the white dot towards the bar, while a computer looks at my brain waves and tries to pick up any signals that appear when I succeed. There's only one problem. I'm not

succeeding. It's incredibly difficult when you first try it, but they say it really can be done, although most people need dozens of training sessions to make it work.

ALAN ALDA This is like lifting things with your eyelids.

ALAN ALDA (NARRATION) But every now and then I did make it happen, and I could see how you could train yourself to succeed consistently.

ALAN ALDA It's more relaxed than being relaxed. It's utter calm, almost nothingness. But there's the sense of doing it, of knowing it will happen.

ALAN ALDA (NARRATION) Andrew Junker is the man who first persuaded people to take seriously the idea that minds can control machines. When we filmed this 8 years ago, he'd been at it for a decade.

ANDREW JUNKER I pick up the electrical signals from the head, connect them to a bio-amplifier, which amplifies the signal 20,000 times, it sends it to this blue box which is the radio transmitter, the transmitter sends the signal to a receiver, which is connected to the computer.

ALAN ALDA (NARRATION) The machine Andrew liked to control was his sailboat. It's about to take a turn around the harbor of St. Thomas, with neither Andrew nor his wife Patricia having to lift a finger. The computer is linked to a motor-driven wheel, and it's getting its signals from 3 electrodes inside Andrew's headband. As with the hat I was wearing, the electrodes are picking up the electrical activity of Andrew's brain. Unlike me, he successfully taught himself to increase or decrease one particular component of this activity. His computer was programmed so that an increase turns the boat to the left.

ANDREW JUNKER I'm turning left now.

ALAN ALDA (NARRATION) While a decrease turns the boat to the right.

ANDREW JUNKER Now I'll turn right. That last experience felt fantastic. 'Cause I felt in a groove. Right here I felt like I was in this slot. As long as I held that slot I could delicately suppress or intensify the signal, and the boat responded. It's a fantastic feeling.

ALAN ALDA (NARRATION) Now, I know what you're thinking. A man sailing a boat in the Caribbean with his brain waves - that's something they expect us to take seriously? But in fact, Andrew Junker's work was then being taken very seriously by - of all things - the US Air Force. Flying fast combat planes is a very complicated business, and the pilot has only two hands and feet to do it. As more and more high tech systems are added, the pilot's in danger of having more

controls to operate than ways to operate them. Which is where Andrew Junker entered the picture. As an Air Force researcher, he set up a laboratory to study brain-machine communication, here at Wright Patterson Air Force Base in Ohio. Pilots like Captain Dave Toomey got pretty good at it, and the researchers were able to measure what was happening fairly easily.

GRANT MCMILLAN Everything you look at out in the world produces a measurable response in your brain. In this case, it's the response of Dave's brain to that light in the cab that's flickering 13 times a second.

ALAN ALDA (NARRATION) The flickering produces in the back of Dave's brain what's called an evoked potential - an electrical signal that can be picked up by electrodes on his scalp. Here's the signal. Keep your eye on the white dot in the middle. Dave's task is to try to change the height of the peak marked by the dot, either increasing it, and holding it there… Or decreasing it, and keeping it suppressed.

DAVE TOOMEY It feels as if you're doing something on a psychic level. It feels like those things you've seen on TV with the Russians bending spoons and moving balls on tables. It feels like that. It feels like it's purely psychic, but in fact it's hard science, it's pure science. It's just using something that the brain does naturally with some very high tech equipment in order to make the link possible -- the human brain-to-machine link.

ALAN ALDA (NARRATION) The machine Dave's controlling is a simple flight simulator. When he suppresses the signal, the simulator rolls to the left. And when he increases the signal he rolls to the right. So far so good. But how does he do it?

GRANT MCMILLAN We don't really know in any detail at all how people do this. How they actually exercise this kind of brain actuated control. And what we usually do when people ask us that question is try to give them an analogy. You know, how does a baby learn to walk?

ALAN ALDA (NARRATION) The idea has now found a new home with our tireless FES research subject, Jim Jatich. The Air Force eventually gave up on the project - not because it didn't work, but because they were concerned it wouldn't work quickly and reliably. But Jim has trained himself to become incredibly good at controlling the dot with his mind.

JIM JATICH When I see it down, I'm actually thinking down or like a fishing weight sinking down to the bottom of a lake. When I'm thinking up, I'm thinking up or like a balloon floating.

ALAN ALDA (NARRATION) It occurred to the researchers that this would make the ideal way to control an implanted FES system. So now instead of thinking about fishing weights and balloons, Jim just has to think… ...close hand. And it really works. It's almost a miracle.

JIM JATICH The first time that I actually opened and closed my hand it didn't hit me when we were doing it in the lab. When I was outside in front of the hospital, you know, just sitting there waiting for my ride to come, it actually hit me that I actually opened and closed my hand by actually thinking about it and then tears came to my eyes. That's the closest thing to what I used to have that God actually gave me, you know. It hit me all of a sudden, and then it was overwhelming, but when I was doing it in the lab it was just another experiment. So I mean, you know, I can't wait to see this developed into something. But it's gonna take time, and a lot of people's effort. I'm ready to go. Yeah.

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