INTERVIEWER: Today is November 16, 2015. I'm Barbara Seidl. And as part of MIT's Infinite History Project, we're speaking with Professor Hugh Herr. Professor Herr heads the Biomechatronics Research Group at the MIT Media Lab, is associate professor of media arts and science at MIT, and associate professor at the Harvard MIT division of Health Sciences and Technology.

His revolutionary work in the emerging field of biomechatronics focuses on developing physically assistive technologies that are intimate extensions of the human body. A double amputee himself, he's hailed as the leader of the bionic age for his breakthrough advances in bionic limbs that emulate the function of natural limbs, and for challenging us to rethink the meaning of disability and the potentials of human augmentation. Professor Herr, thank you so much--

HERR: Thank you.

INTERVIEWER: --for speaking with us today. So it's well known that you are a prodigious climber, and have been since a very young age. And I wonder if you would take us back to growing up in rural Pennsylvania, and what it was that got you started in climbing-- got you started to being the person you are now.

HERR: My parents were adventurous, and that led the family every summer to going on extended road trips across North America, often three-month trips out to California and then into Canada and to Alaska, often. And in those trips we would hike and canoe and fish. And the adventure became more and more pronounced. And the walls became steeper and steeper. And eventually, when I was 11, I was climbing really quite high mountains across North America. So that created a context for extreme sport, for pursuing the vertical world of rock and ice climbing.

INTERVIEWER: And was this something that you did with your other siblings?

HERR: I'm the youngest of five. I have two brothers and two sisters. My two brothers teamed with me to do a lot of the very severe, steep climbing. My sisters did some hiking, but never took part in really the vertical rock and ice climbing.

INTERVIEWER: Do you remember your first particularly vertical climb, your first really challenging climb as a kid?

HERR: I began climbing at the age of 7, and the activity became obsessive probably at the age of 8. An early memory is I was with my brother Tony. He's the oldest of the siblings. And I had climbed up a vertical wall, I don't know, 20 feet, and I got stuck, and he climbed up to get me. And he was holding on to my arm, and the other arm was holding on for dear life to the rock face. And I think we both tired and fatigued and both fell onto the ground. It was quite sad.

INTERVIEWER: And you were both all right when you fell?

HERR: Yeah, I believe so. It's somewhat remarkable that I've survived my childhood. It was endless adventure.

INTERVIEWER: Can you say more about that? What other kinds of adventures? I know about the rock climbing, but I don't know about the other--

HERR: Oh, gosh, when I was an infant, Hans and Tony, my brothers, decided to carry me down to a woods area adjacent my family's farmhouse. And they just sat me down in the floor of the forest and were playing, and the German shepherd pet was running around. And I think the German shepherd knocked off a hornet's nest about that big, and it landed right next to me. And my brothers tried to get me, and couldn't withstand the pain of being stung.

So they ran the whole way up to the farmhouse to get my mother, and the whole way back down my mother ran, and she just took her apron and kind of put it over her head and grabbed me and rushed me to the hospital. There were wasps like way into my ear canal, up my nose. She was slapping me continuously to stay awake.

INTERVIEWER: Oh my goodness.

HERR: So that's how my life began.

[LAUGHTER]

INTERVIEWER: So adventurous early on and not entirely voluntarily.

HERR: Right. There's many stories.

INTERVIEWER: It sounds like. And I understand that you were raised in a Mennonite family, is that right?

HERR: Yes. On a large Lancaster County farm with corn and alfalfa, tobacco, and tomatoes. Yeah, I worked very, very hard as a child. I would come home from school and claim that I was sick. And my father would look at me and say, you're not sick. Get out. Get out in the fields. I need your help.

INTERVIEWER: So where in this hardworking, adventurous upbringing did an interest in science and physics and math, where did that come in?

HERR: It didn't. I was-- I mean, by probably as early as 8 years old, my goal was to become the best climber in the world. And that was a singular focus throughout my tweens and teens. The interest in science, engineering and design came after my mountaineering accident, when I witnessed the pathetic prosthetic technology that was available in the world and decided to do something about that.

INTERVIEWER: Can you go back and tell us briefly what happened in the accident?

HERR: I was 17 and I set out with my climbing partner at the time, Jeff Batzer. We drove to New Hampshire. And our goal was to climb the ice faces up Huntington's Ravine and Mount Washington, and perhaps go to the summit. And we slept that night in a hut, and the next day headed out and climbed O'Dell's Gully, and the weather got worse and worse.

We successfully climbed the 800-foot ice face, got to the top and huddled together behind a rock face, and made the decision to go towards the summit in ever-worsening weather conditions. And even though we walked just five minutes above the Huntington's Ravine, it was enough to become disoriented. The conditions worsened to become what's called white-out or blizzard conditions, where even if two people separate by four feet, they're not able to see each other.

So we became disoriented and descended down a region of the mountain that we had-- that was distinct from where we climbed up. And that region was the Great Gulf, which is the worst side of Mount Washington one could be in during winter months. It's horrendous bushwhacking. The average depth of snow was to the waist, sometimes to the chest. The tree limbs came right down next to the surface of the snow. So you had to-- one would have to tunnel through the snow to make any progress.

So we hugged a river where one could maneuver somewhat. But of course we fell in on occasion and got our lower legs completely soaken in minus-20 degree Fahrenheit temperatures. So frostbite set in. Hypothermia set in. And we were out there nearly four days, and were-- got within a few miles of a roadway and couldn't walk. And we were discovered by a person out snowshoeing, Ken Bradshaw, and hours later plucked from the mountain via helicopter.

And then what began was months of surgeons attempting to save my biological limbs. And that effort was abandoned about March. The climb was in January. And both my legs were amputated below the knee due to tissue damage from frostbite.

INTERVIEWER: And so the grand plan to be the best climber in the world changed.

HERR: Well, there was I guess a semicolon, perhaps. And most people believe that my climbing career was over, and my father said that if I wanted to climb, I should do so. And I went-- my limbs were amputated in March. I went to a rehabilitation center in May, where I was to receive my first pair of artificial limbs. I was there for just I think two weeks, and I went home for the weekend. And during that weekend I went climbing with my brother.

I could barely walk. I crawled-- practically crawled to the base of a vertical cliff. But once I got onto the vertical world again, I felt at home. I felt free again. And I was reminded of my desire and passion to be a climber. So that led into this very aggressive adventure to return to sport with my new body, without biological lower legs.

That was a technological arc. I quickly-- initially, one tries to make these artificial limbs look like biological limbs, but I quickly abandoned that notion, and told myself that what mattered was function, and they need not look human. So I asked the question, what is kind of optimality for climbing rock and ice surfaces for lower limbs? And what I ended up with was distinctly non-human.

You know, the foot didn't have a heel. It was the length of a baby's foot. It was-- its angular orientation relative to the longitudinal axis of the leg was odd. It's not something one could walk in. That was one foot. And I made the feet interchangeable. And I had feet for ice climbing with spikes. I had feet for climbing rock fissures with a wedge shape and vertical blades that are coated with compliant rubber. I made my height adjustable. I could be probably 4-foot-5 up to whatever height I wanted to be given that both my legs were amputated. So through that, it was only 12 months post the amputation surgery that I was climbing at a superior level than I had achieved before the accident with biological limbs.

INTERVIEWER: So these were things that you were designing yourself, figuring out for yourself shortly after your accident at age 17?

HERR: Correct. So in high school, I had-- I actually half the day went to a vocational school, where I learned tool and die, the tool and die trade, basically how to make things out of metal and wood-- so lathes and milling machines and whatnot. So that basic machining skill set was helpful in designing these limbs.

INTERVIEWER: I want to go back one step to your father, who when you came home, he said if you want to climb, you should climb.

HERR: It was actually when I was still lying in the hospital bed.

INTERVIEWER: When you were in the hospital, he said, while you're in the hospital bed, just having had both legs amputated, he said, if you want to climb, you should climb.

HERR: Correct.

INTERVIEWER: Can you tell me more about this man and his influence on you?

HERR: My parents were very insightful. I mean, a typical parental response would be you are not getting anywhere close to a mountain ever again as long as we're in command of you. But that-- they knew climbing was my life's passion. And by saying that I was not allowed to pursue such activities would have driven a lot of anger and depression. So they took the opposite view, and said that if I were able, I should. And the level of therapy and healing that emerged from that rebirth, from returning to the mountains, was extraordinary.

INTERVIEWER: So it was being able to get back on the mountain again that helped.

HERR: Back on the horse. It's a very American story.

INTERVIEWER: It is.

HERR: You fall off the horse, and you get on again. Pull your cow boots on and go.

INTERVIEWER: And go faster.

HERR: Go faster.

INTERVIEWER: Get on the horse and go faster.

HERR: That's a very American mythical story.

INTERVIEWER: But it improved your climbing.

HERR: Right.

INTERVIEWER: Were there other people in your high school or in your childhood that were persuasive? This is a tremendous amount of drive in a 17-year-old, starting with a 7-year-old and then an 8-year-old, a tremendous amount of drive to have that focus. This is what you wanted to do. In a classic storyline, you've hit a major obstacle and overcame it. Were there people who helped you be that focused and that determined?

HERR: I think it's an innate behavior or property that I just-- I think it's part of my genetics. So I would say people-- there are certain people, such as my parents, that allowed me to be odd. And odd I was. As a child, I would just sit alone and rock and stare into space for hours. And what I was doing as was imagining a future. I lived in the future. So I was imagining greatness. The rocking was just soothing.

INTERVIEWER: What future did you imagine?

HERR: Just feelings of grandeur. Perhaps delusional.

[LAUGHTER]

INTERVIEWER: So fair enough. So I'm gonna take us back to where I pulled you away from. So you're 17. You've designed your first legs that you've designed for yourself, right, and gone climbing again, and gone faster and farther than ever before. Is it there, at that point, that you're deciding to go to college, or is that when you went to, is it Millersville?

HERR: Yes, Millersville University. So most adults in my family, males in my family are-- pursued kind of the trades, the crafts, the construction careers. And I tried that using artificial limbs, and it wasn't a whole lot of fun, because limbs back then and still today can be very uncomfortable to stand and walk for long periods of time. So this notion of being on a construction site standing and walking all day long was not fun. So there was that piece or that motivation.

It was also the motivation of wanting to improve the technology that was available to me and the arena of prosthetics. And there's also the motivation of simply being tired of being an extreme athlete, of the danger, of constantly worrying about injury, which all athletes face. If I just-- if I blow out a tendon, my career's over. That's a level of anxiety that's difficult to live with for a decade plus.

So I was-- I wanted to do something very, very different with my passions. And so that led me to going to college. And that was difficult because, because of my athletics focus, I didn't know what a percent was. I didn't know just very basic concepts. So I graduated from high school, and if you were to ask me, what's 10% of 100, I would have no idea.

So to enter college I had to, and I did in fact buy just basic mathematics books and studied on my own. And it was only two years from that point of not knowing what a percent was, where I was in college studying quantum mechanics. It was this extraordinary intellectual rebirth.

INTERVIEWER: And was that just focus at home with books?

HERR: Alone.

INTERVIEWER: Alone.

HERR: In a room.

INTERVIEWER: Rocking in the corner with the book.

HERR: Correct. Same.

INTERVIEWER: Oh my goodness.

HERR: Instead of staring at-- we used to have this handmade carpet that-- where the thread started in the middle of the carpet and kind of spiraled out. So when as a child, when I'd rock, I'd look at those spirals. And then later, it was, yes, it was the quantum mechanics books.

INTERVIEWER: And so then settled on a degree in physics.

HERR: I first pursued computer science. And I learned a few languages. And I got bored. I started to see this very, very basic patterns from computer language to computer language. And it just seemed too narrow of a focus. So I changed to physics.

INTERVIEWER: And when you make that change to physics, did you still-- did you have your head and your heart on the redesigning of these--

HERR: I did. But also, when I picked up those mathematics books and physics books, I just became enthralled. I absolutely loved the material and learning the material. So it was very-- yes, there was this improved technology goal. But there was also this just complete happiness and passion that I felt from learning the material. And it's interesting that it really replaced my passion for climbing. I didn't have an intense desire to go climbing. So it was unusual.

INTERVIEWER: How did you find physics? You were in computer science, and how did you know to make the shift to physics?

HERR: That's a good question. I knew physics was a description of the natural world, and computer science was a description of a type of machine. So it just seemed if I was going to be serious about designing body parts, it should probably be physics as the foundational science.

INTERVIEWER: That that would reconnect you to the natural world, which had also been something you were connected to since a kid, the natural world.

HERR: Right.

INTERVIEWER: And that continued through.

HERR: Right.

INTERVIEWER: Fascinating. And at what point in this journey did the idea of, I know I'd like to go to MIT-- where did that come in?

HERR: So I went to and got an undergraduate degree in physics from Millersville University. I wanted to continue. Wanted to go to graduate school in some area of science or engineering. And I believe I applied to three schools, University of Pennsylvania, University of Colorado at Boulder, and MIT.

University of Pennsylvania, I don't think I ever would have gone there. I think I was accepted into all three and nearly had a nervous breakdown deciding between MIT and University of Colorado at Boulder, because I just-- my climbing days, Boulder was kind of the Mecca and the place to live in the United States. And I think it was a girlfriend who decided for me.

[LAUGHTER]

INTERVIEWER: Did she just look at the options and say, this is what you're doing?

HERR: Say, what are you, stupid?

[LAUGHTER]

INTERVIEWER: Of course you're going to MIT.

HERR: Right.

INTERVIEWER: Well, that was convenient and helpful of her.

[LAUGHTER]

HERR: I know. Yeah. Bless her soul.

INTERVIEWER: And so, small-town boy growing up on the farm in Pennsylvania, going to the small, local, public university, and then you're moving to Boston and showing up at MIT. What was that like to land there?

HERR: Well it's-- when I arrived at MIT, finals were just getting started. 'Cause when you're in the buggy and you go, it takes a long time. Just kidding.

[LAUGHTER]

Yeah, it was-- so Millersville University, the physics department is very, very good. It's-- and it's a remarkable educational deal because the physics classes are not hundreds of students and one professor and three TAs. The classes are five students, eight students to a professor, and very, very extraordinary physicists. So I had this wonderful undergraduate education, very challenging education.

So when I came to MIT, I mean, it was scary because it's MIT, but when I started the courses and I took the exams, it was just nothing new. It was basically the same difficulty. Which I'm really thankful for my undergraduate professors, that they made it that hard. Because most people are completely shocked when they come to MIT.

INTERVIEWER: Were you shocked that you were that prepared?

HERR: I believe I was. And it was a pleasant surprise, for sure. It was just-- it was kind of like this again. So that was helpful.

INTERVIEWER: So when you first got here, you have that foundation behind you, and you had this passion for wanting to change the way things work. And you had studied the natural world to make it more possible for you to be able to do that. What did you first dive into? What first got you started here?

HERR: What project, or--

INTERVIEWER: Yeah.

HERR: So I-- in my application to MIT, I described a design for a mechanical interface between a prosthesis and the human body, a socket, where there's fluid bladders and pressure sensing and pumps and actuators to vary the pressure field around the residuum. And I think Woody Flowers liked that idea. And so I was mentored by Woody. And it turns out we didn't pursue that that particular problem, but during my master's, I worked on actually augmenting human physicality with elastic mechanisms.

So I became intrigued with mechanisms like the catapult mechanism, where you can amplify human power with an elastic device, and actually came up with new forms of how humans can be augmented in my master's degree. Then I went to Harvard and studied under one of the architects of the field of biomechanics, Thomas McMahon, and then came back to MIT for a post-doc and the leg lab, and started by own lab. So it's really been, for a very long time, I've been bouncing back and forth between Harvard and MIT.

INTERVIEWER: For the lay person who has never thought about any of these things, could you define biomechatronics for us?

HERR: Well, obviously it's the mergence of biology and synthetics or mechatronics. So bionics is the term typically used, at least once upon a time in Hollywood circles. So biomechatronics is kind of the academic term for what people know to be bionics.

Bionics or biomechatronics is really an interplay between biology and design. And some people extend that to say interplay between nature and design. And it's bi-directional. You can inform synthetic design through biological or natural principles. And you can also design nature, and in areas for example of synthetic biology. So it's-- the world now is actively pursuing this notion of bionics, and that interplay between nature and design.

INTERVIEWER: Can you say more about how one influences the other?

HERR: There's the idea of biomimetic design, using principles of biology to inform the design of a synthetic construct. And there's also synthetic biology or tissue engineering, where we actually design new biology. So again, it's bi-directional. But in my opinion, bionics does not describe exclusively domain of synthetics, but also includes biologics. It's the design world as it mingles and is embedded into biology.

INTERVIEWER: I know you've had tremendous, well-recognized success in your work, clearly. And I know that you hold or co-hold about 10 different patents with a number of others.

HERR: Oh, no, it's probably over 100 at this point.

INTERVIEWER: Over 100 at this point. I stand corrected. Of those over 100 patents that you're holding at this point, which were the ones that were most challenging for you to achieve, and which ones were most meaningful for you to achieve?

HERR: For me, getting a patent is not terribly difficult. That is to say, an invention is fairly simple. Innovation is very, very hard. But invention is not. So I've only a few times in my life actually innovated, where I along with my team engineer something and people use it in the world in kind of a mass production. So that's very difficult.

So as scientists and engineers, we can change the world by expanding knowledge. And we can also change the world by actually putting technology into the world. So I like trying-- I try to do both. But actually changing the world by real physical constructs that were once in your imagination is very, very difficult. And the timescale is-- it takes me at least a decade every time every time I birth a new technology.

INTERVIEWER: Of the new technologies that have been birthed, which one do you think has the most meaning for you-- has created the most change that you've seen?

HERR: There's an artificial knee that I helped develop, and an artificial ankle, both prostheses. I think the bionic foot-ankle, which its commercial name is the BiOM foot-ankle prosthesis, is more interesting and has had a more precipitous impact on the world than the computer-controlled knee that I developed.

INTERVIEWER: And can you tell me more about that knee?

HERR: The knee?

INTERVIEWER: Yeah.

HERR: So the knee, the commercial name is the RHEO KNEE. And it's manufactured and distributed by an Icelandic company called Ossur. Ossur's the second-largest prosthetics and orthotics company in the world. And believe it or not, they're in Reykjavik, Iceland.

So it's a computer-controlled knee that adapts automatically to a person's movement desires, how quickly they move and whether they move across terrain or whatnot. So there's an algorithm that adapts and changes the resistance or the dampening profile of the knee as a person goes about their life.

INTERVIEWER: And is that a computer program that allows that change?

HERR: Yes. And the actuator or the variable damper uses magnetorheological fluid, so it's an oil-based carrier with small metal or iron particles suspended in the fluid. And if you put a magnetic field across the fluid, it stiffens. So by doing that, you can vary resistance or dampening about a joint.

INTERVIEWER: And I understand there's a wide variety of prosthetics that you've designed for different purposes-- that some are waterproof and some are for running and some are for dancing.

HERR: Yeah, for small numbers of people. I mean, my climbing legs were initially just for me, and a few people have used those climbing device designs. But in terms of kind of a large number of people, I've focused on prostheses that are really designed for a common activity such as walking.

INTERVIEWER: And so it sounds like that's part of the focus moving forward, is taking what all you've developed and making it available to more people, and making it more accessible. Is that right?

HERR: That's right. And it may surprise some, but even walking on a flat surface is still challenging with today's prosthetic limbs, and also orthotic or braces. We're getting there, but the bionic foot-ankle device that my team has developed was the first prosthesis in history to normalize walking speed, metabolism, and some measures of muscle skeletal stress for walking. So that just occurred a few years ago.

INTERVIEWER: I am surprised that it is difficult to walk with prosthetics that aren't like the ones designed by your lab. Why is that?

HERR: The biological body is extraordinary. Biological materials are remarkable in their adaptiveness, their strength, their power output, their weight, their volume. So it's difficult to take synthetics and emulate that capability.

So the human foot-ankle complex is-- we all know its basic volume. It's not a large device. But it's-- the ankle is very, very powerful. When an adult walks quickly, the ankle is approaching 1,000 watts of peak power mechanical. That's very hard to engineer in a small package that would fit into a human foot-ankle morphology.

And what makes biology very extraordinary is its adaptiveness. If you spend $50 million and develop any type of biomimetic joint-- a knee, an ankle, an elbow-- it'll take that scale of effort to engineer it to go 5 million walking cycles, which is about four years of a person's life, before it breaks.

So the human system, sometimes our bodies go 80 years without any adjustment. We're nowhere close to that in the engineering world. We have not a clue how to build machines that are that robust. And biology does it by continually adapting and healing and fixing.

INTERVIEWER: So it sounds like it's a matter of continually adapting and healing and fixing the technology.

HERR: There are people working on that, yes.

[LAUGHTER]

INTERVIEWER: More than a few, I would imagine. I wanted to go back a moment. When you talked about starting the lab here at MIT, it seems unusual that there's a media lab and then a biomechatronics lab together, that there's that particular collaboration. Can you say a bit about that?

HERR: I think you might be misinterpreting the word media. So media in the modern Media Lab is media like materials. And perhaps the perception is that it's media like television and radio, although its early history was certainly focused on that type of media.

The media lab has a long history of human augmentation through wearables. So Sandy Pentland, for example, and Pattie Maes and others were doing things that look an awful lot like Google Glass today. So wearable computers, sensing, and enhancing humans cognitively was a very dominant theme in the Media Lab prior to my arrival. So I think generally the notion of bionics is completely natural in the Media Lab arc.

INTERVIEWER: Thank you. I just want to take a quick peek here.

So one of things I want to be sure to talk to you about-- you have been affiliated with MIT in some way or another for over 20 years at this point. And this year, as you may know, marks 100 years of MIT being in Cambridge. And I'm wondering from your perspective how MIT has changed over the last 20 years or so, and how MIT's relationship with Cambridge may have changed, how they influenced each other?

HERR: Oh gosh, I mean, in the modern era of MIT, of course, you've seen this extraordinary convergence of biology and engineering. And that's-- a lot of hay has been produced from that mergence. And human bionics is just one realm of that mergence. And it will continue on and on and on. So I think that'll be a very dominant theme moving into this century for MIT.

Relationship with Cambridge-- I mean we just continually expand outward. It just seems like every month there's a new building. So just in terms of enough space, we're going to have to think very carefully of how to expand MIT in terms of footprint.

INTERVIEWER: Thank you. And I also wanted to ask over your 20 years at MIT how your experience of teaching has changed, and how your experience of working with students has evolved over those years.

HERR: I think the classroom at MIT has transformed from kind of a classic 1950s model of teacher and students, where the students are all sitting and peering up at the professor, to more and more the classroom being very active, very creative, where students are building things. So as they're learning about calculus and principles of biology and principles of physics, they're immediately applying those principles, those learnings, to their own projects, their own constructions, their own creations. So I think that model of hands-on education literally is, will be and is starting to become a revolution in how young minds are trained.

And the whole notion of interdisciplinary work has also been a powerful influence on the way we teach and the way people are learning. So this elimination of silos defining formal disciplines is very, very exciting. And a lot of the interesting research questions and solutions occur at the boundaries between formal disciplines. So the melding of formal ways of thought has led to a modern-day Renaissance. And you're seeing that across the Institute, not only in research laboratories but also in classrooms.

INTERVIEWER: And how has that melding influenced your work, that cross-disciplinary approach?

HERR: Oh gosh, I mean, we are designing and fabricating body parts for humans. It's intensely multi-disciplinary. So in my lab we have physicists, we have electrical engineers, mechanical engineers, artists, designers, people that are just interested and are not trained in really anything but are jumping into the hot seat.

So when you build body parts, it goes beyond fashion designs. Aesthetics are critically important. And that the duality between human aesthetics and the aesthetic of a machine is an interesting interplay and design.

INTERVIEWER: I know you've spoken in the past about how there's an inclination to make it beautiful from a-- in a human way when it could be beautiful in a machine way, and to not-- can you say more about that? Can you speak to that?

HERR: Well, from a design perspective, my goal is to make the bionic body part a similar shape to its biological counterpart, but to not look human at all-- to not look biological at all. And I do that because I want the user of the bionic limb to explore the duality between human beauty and machine beauty.

So maybe one evening, their mood takes them to wanting to look human in that part of their body, and then they pull on an artificial skin, and because it's the same shape as a biological limb, no one can even tell that that part of their body is synthetic. And then maybe the very next day, they go to a funky party and want to explore this notion of human-machine beauty. So allowing that interplay to be expressed in the users is kind of a one key design focus to my laboratory.

INTERVIEWER: We've talked a bit about prosthetics. We haven't talked much about the exoskeletal projects that you're working on. Can you say a bit about what those are, and what role you see them playing in the world?

HERR: So when one designs a bionic joint prosthetically, to be used by a person that's missing a biological limb, one ends up knowing a lot about that joint in general. So let's say it's a knee. When you understand the fundamentals of a knee, you can use it prosthetically or you can use it orthotically or exoskeletically. So that is to say you could go from a prosthetic knee that's for a person that's amputated above the knee to a bionic structure that wraps around a limb that applies forces and torques on the limb to augment a person's physicality that has a biological limb. So we do both.

And we develop both orthoses and exoskeletons. An orthosis is a medical device used to assist a person with some limb pathology, where an exoskeleton attempts to augment normal human physicality. So it wraps around a biological limb that has no impairment whatsoever.

So we were the first group, research group in the world, in 2014, to build a leg exoskeleton to augment normal human physicality in something as common as walking. So we were able to lower metabolic cost for walking with a worn exoskeleton. And that effort and technology goes back well over 100 years. There's patents that one can find of exoskeletons that seek that purpose of lowering energys to walk and run. So it's taken over a century to actually achieve that goal.

INTERVIEWER: 100 years ago, we were trying to decrease the metabolic cost of walking?

HERR: Yeah, there's actually a patent by an inventor in Russia, before the Soviet Union-- an inventor that was thinking about how to augment the Russian army. This is under one of the czars of Russia, and had really a remarkable exoskeletal design. And there's a picture in the patent of a person running in the exoskeleton with the classic mustache. That's my favorite patent.

INTERVIEWER: The patent that comes with the mustache.

[LAUGHTER]

And so I'm assuming because this was connected to the Russian army, the hope was just to make it possible for people to walk a longer and farther with less wear and tear. Does this--

HERR: Well, his objective-- Yagin was his name-- was to augment the Russian army. So his vision was that soldiers could run with very, very low energies-- run with perhaps not even breathing hard, and over very irregular, rough, natural terrains. Which is an extraordinary goal, and it's been my goal as well for decades.

INTERVIEWER: And then this was developed in 2014.

HERR: Yeah.

INTERVIEWER: It exists now as of 2014.

HERR: It exists for walking, and now we're pursuing running. So yeah, my vision is-- my hope and my dream is that you walk down the streets of Boston, you walk across the MIT campus in 10 years and it'll be routine to see people wearing bionic structures augmenting their physicality. Maybe they have a knee injury and they want to protect their knee. Maybe they don't have any injury whatsoever and they just want to get there fast.

INTERVIEWER: So you could get yourself over the Charles much, much faster with one of these things.

HERR: Absolutely. There'll be a time where it's just hard to comprehend that bionics isn't pervasive in the world. It's going to be like automobiles, this notion of augmenting our natural morphology. And going beyond these large metal boxes with four wheels and extending the capabilities of our legs and our arms will just be commonplace, I believe, in the future.

INTERVIEWER: It's taking this love of extreme sports that you started with as a kid and making it extreme day to day.

HERR: Exactly.

INTERVIEWER: That we can move faster--

HERR: Yeah, my broad goal is to make humans superheroes. And we'll get there.

INTERVIEWER: Speaking of human superheroes, I wanted to talk to you a little bit about the No Barriers Boston and the work that you did after the Boston Marathon. So can you tell me a bit about your thoughts in creating No Barriers Boston and the work--

HERR: So the No Barriers Boston Fund, the focus of those monies is to pay for prosthetic devices for persons that lost limbs in the Boston terrorist attack where the prosthetic devices extend one's ability to pursue athletics or the arts-- arts being dance. And there's a very practical motivation for doing that. It's hard to get an insurance company to pay for such limbs for athletics and the arts. So we thought it valuable to create that fund to help as many people as we're able to get such limbs, that are so freeing.

A lot of the people that lost limbs in the Boston terrorist attack were artists, were athletes. And to give that passion up is something I deeply understood as just unacceptable. Life needs to continue, and people need to continue to express.

INTERVIEWER: I know there's one dancer in particular who you worked with. Can you tell me about meeting her, and the work that you did there?

HERR: So we've worked with a number of people that lost limbs in the Boston terrorist attack. One person is Adrianne Haslet-Davis. We worked with her in the laboratory here at MIT to develop a limb that's demonstratably improved for dance. So we focused on the genre of ballroom dance, and we wanted to see, could we develop a control algorithm for a powered foot-ankle and enable something like a cha-cha or these various forms of ballroom dance? A paper was just published on that work, so I'm very excited about that publication, because it really-- most prosthetic design is for repetitive activity such as walking, and dance represents this new frontier of non-repetitive, highly volitional movement patterns.

We've also worked with others that lost limbs in the Boston terrorist attack. We just-- we fit a young girl recently with a leg that enables her to swim and to run across the beach. And so it's been very rewarding.

INTERVIEWER: It sounds like it. One of the things I have heard you say in the past is that no human is broken. It's the technology that's broken. Can you elaborate on that?

HERR: When I lost my lower legs to frostbite, I was-- the months following the amputation surgery, I was told that I was courageous for trying to climb again. And that word courageous in that context is demeaning. You would never say to a top athlete that they're courageous. So it means like, you're probably going to fail, but man, you have a strong spirit, and man, thank you for trying. It doesn't underscore any abilities or innate talents.

It's very interesting, in the 12 months immediately following my amputation surgery I was courageous, and then the moment I began climbing at a level that was superior to persons with biological limbs, I no longer was courageous. I became a threat. And a few fellow climbers actually threatened to cut their own legs off to achieve my unfair advantage. So that psychological arc on identity and identity of self and how society views an individual is really fascinating. And it's this extraordinary interplay between the individual society and technology. We've seen it play out a few times now in human history.

Another classic case is Oscar Pistorius. He was winning everything in the Paralympics, and I think he got bored and started to run-- just show up at sprinting races outside the-- against persons with quote unquote normal physiologies. And he would on occasion win those races. And that got the attention of the IAAF, the governing body of sporting events such as the Olympics. And they rushed to judgment, claimed that he was cheating and banned him from the Beijing Olympics. And they said, Oscar, if you show up and you qualify, you're not allowed to take part in the Olympics.

So naturally that got the attention of the legal community and the scientific community, and we eventually got it appealed. But it's extraordinary. Society views an artificial part of the body as less human than the biological part of the body, that somehow our cells and tissues are godly and deeply human, and the atoms that make up synthetics are somehow less human and less godly. And it's a threat when someone like myself has a major part of the body that's synthetic that climbs better than a person with a godly, natural body. There's something that's very upsetting to some types of individuals.

And you saw that play out on the world stage with Oscar Pistorius. There are high-ranking officials in the IAAF that said we cannot let Oscar compete in the Olympics because he will destroy the purity of the sport-- the same language used against women and persons of color. Absolutely extraordinary.

So there-- we will-- as we march into the century, there'll be a shift in consciousness away from that obsession about what we're made of, that distinction between our biological bodies and our synthetic bodies, to it not mattering anymore. If I could race 50 years ahead and I could give you a bionic, synthetic arm that works as well or better than your innate biological arm, it really won't matter that it's synthetic. It'll just-- all that will matter is your quality of life and your expression as a human being, not what you're made out of. Now it matters. So that shift is happening right now. And it's completely fascinating.

I call it the death of normalcy. And what I mean by that is if we can extend our physicality into all different forms of morphology, if you want another arm, you can have another arm. If you want to run faster, you can run faster. Where our bodies become sculptures, malleable sculptures, that's where we're moving as a race, human race.

Right now, we have a very narrow view of what beauty is. A woman has to be this and a man has to be this, which is a horrible world to live in. Women think they need to look like that, and men think they need to look like that. There's this whole problem of body image. But I think with bionics and extending human capability through bionics and through design, by integrating the built, design world with our very bodies, we'll just break those narrow frameworks down of what we view as beautiful. Because in that world, you can have a body that doesn't look like a human body, and still be powerful and sexy and relevant. So that's exciting to me.

INTERVIEWER: You had talked about ending disability. Is that some of you mean by ending disability?

HERR: I mean, approaching half the world's population has some condition that results in a quality of life that's unacceptable. So broadly speaking, across physical, sensory, cognitive, social, emotional, there's many, many conditions in the world that result in disability. So a wonderful use of technology is to eliminate disability.

Using my body as an example, you cannot with a straight face say that I'm disabled. I climb mountains. I run. I play tennis. I do whatever I want to do. But that's-- when I say me, I'm a human-machine interaction. If you take the machine away from my biological self, I'm completely crippled. All I can do is crawl. But with that human-machine interaction, I'm freed from the shackles of disability.

So that-- what's happened to my own body, if you extend that across all conditions, I believe we will easily eliminate disability in this century. And that science and technology that enables the elimination of disability will largely be the same science and technology that's foundational for human augmentation, extending human capability beyond what nature intended, not only physically but cognitively as well.

INTERVIEWER: Gonna stop there. Thank you so much.

HERR: Oh, great. That was over an hour?

INTERVIEWER: Did you have other things you had wanted to say?

HERR: No, that's fine.