MUSIC IN

NEIL SHUBIN VO/OC
When I look at my fellow humans, I see ghosts of animals past. Glimpses of an epic story that's hidden inside us all. My name's Neil Shubin. As a scientist, I look at human bodies different from most people. The way we grip with our hands, we can thank our primate ancestors for that. How we hear so many sounds, that dates back to creatures the size of a shrew. And the further back we go, the stranger it gets. To reveal why we look the way we do, we'll travel through the distant reaches of our family tree and meet an unusual cast of characters. The ancestors that shaped your body. The family you never knew you had. From the badlands of Ethiopia … She's beautiful. …to the shores of Nova Scotia… This is the spot. …we'll search for clues that lie buried in rock. His eyes are like globes and he's like, "I found it, I found it." …and search for answers written in our DNA.

PETER HOLLAND VO
I think it gives us a glimpse into the brain of our ancestors.

NEIL SHUBIN OC/VO
I mean, I find that mind-blowing. The adventure begins with a search for some of our most elusive relatives , fish that crawled onto land hundreds of millions of years ago. From our necks and lungs, to our limbs and hands, we owe a lot to these intrepid pioneers. So if you really want to see why you're built the way you are, it's time to meet your inner fish.

MUSIC OUT

MUSIC IN

TED DAESCHLER VO
Wow, look at that. Paradise.

NEIL SHUBIN VO
Yeah.

TED DAESCHLER VO
That is perfect.

NEIL SHUBIN OC/VO
He's going right up the valley. The Canadian Arctic is one of the most desolate regions of the planet , but there's nowhere else I'd rather spend the summer.

NEIL SHUBIN VO
What draws me here is treasure – my kind of treasure: fossils hidden inside ancient rocks. In particular, the fossils of long dead fish, but not just any old fish. I'm hunting for fish that carry the story of our own bodies inside of them . How I got here and what I found could change the way you think about yourself and your body.

NEIL SHUBIN VO
This is a story that ends on top of the world with the most important discovery of my life. But it begins in the city of Chicago, with a room full of human cadavers.

NEIL SHUBIN VO
It was more than a decade ago, and I'd just moved to the University of Chicago as Chairman of the Anatomy Department . And I remember, you know, hanging around with the students around the tables here, just getting to

know them and letting them get to know me. They're launching their careers as future physicians and there's some nerves and skittishness those first few days…

MUSIC OUT

NEIL SHUBIN VO/OC
…and they'd almost invariably ask "Dr. Shubin, what kind of doctor are you? You know, are you a surgeon? Are you a cardiologist?" And I'd say "Well, no, I'm a fish paleontologist." And I'd get this look like "What? I want my money back." But it soon became clear that being a paleontologist, and not just any paleontologist, a fish paleontologist, is a very powerful way to teach human anatomy. Because often some of the best road maps to our own bodies are seen in other creatures .

MUSIC IN

NEIL SHUBIN VO
Now you might not think your body has much in common with a fish, but I see a family resemblance. On the surface, you are not very fish-like, I'll admit. But you are related to them. And the clues to that connection are etched in ancient stone .

NEIL SHUBIN VO
Fossils unearthed around the world reveal that fish are the first creatures with bony skeletons. They have backbones and skulls, just like you and me . This shared anatomy connects us to fish and to a long line of other animals. To see what I mean, imagine the complete history of life on a giant family tree, from the first microscopic organisms billions of years ago, to all animals alive today .

NEIL SHUBIN VO
Our history lies on one branch of this tree of life, and we can trace our ancestry back. Around 400 million years ago, you'll find fish swimming in oceans and streams . 40 million years later, the first amphibians appear on land . Then we see reptiles , followed by the first mammals around 200 million years ago . And much later, we arrive at our special branch: primates . This history tells us something remarkable. Every reptile, bird and mammal alive today is descended from ancient fish, and that includes us .

MUSIC OUT

MUSIC IN

NEIL SHUBIN VO/OC
So how does this legacy play out in our anatomy? Each one of us, walking around in this lab today, carries the history of life within us. And the evidence is seen in every part of our bodies. And not just in our bones. Even the complex tangle of nerves inside the human head makes much more sense when you realize it's the same basic wiring found in fish . But there's one defining piece of human anatomy that seems remote from the world of fish. And I vividly remember when it first captured my imagination. When I walked into the anatomy lab for the first time, I was sort of scared about what I was going to see, what I was going to feel. But the reality is, after the first few weeks, that fear turns into a sort of a cocky self-confidence.

MUSIC OUT

NEIL SHUBIN VO
And these things, you know when you dissect them, it doesn't look very human, it kind of looks like a wax model in a lot of ways, but then you hit the hand.

MUSIC IN

NEIL SHUBIN VO/OC
And for me, as I unwrapped the gauze and revealed the palm, the fingers, the fingernails, something else hit me entirely. And that was a deep sense of connection, a connection to another human body lying on that slab. This was not a wax model that I was dissecting, this formerly was a person who lived a life just like I am living now. When I see the anatomy within the human hand, I'm in awe of the intricate connections between bone, tendon and muscle . Really it's through the action of these muscles through the tendons that the hand does its, you know, does its magic, if you will. So that when the muscles fire, it pulls on these tendons and watch, the fingers flex.

MUSIC OUT

NEIL SHUBIN OC/VO
Now, the fine muscles of our hand, these little tiny muscles that lie along the tendons? These are the muscles that control the fine motion of our fingers. These are the ones that are quintessentially primate and human.

MUSIC IN

NEIL SHUBIN VO
So where did this marvel of evolution come from? It clearly has deep roots in the past.

NEIL SHUBIN VO
And you can see evidence of that in the bones of modern creatures. More than 150 years ago, scientists were finding connections between the hands and limbs of four legged animals .

MUSIC OUT

NEIL SHUBIN VO/OC
Sir Richard Owen was an anatomist in the 19th century; he was fortunate to be an anatomist in an age of discovery.

MUSIC IN

NEIL SHUBIN VO
And so people were coming back to London with new and oddball creatures for him to analyze, and in analyzing all the different creatures he found common patterns. Although the overall shape and structure of each limb was very different, he started to see that there was an underlying theme. It was as if the same set of bones was being squashed or extended to perform different functions.

NEIL SHUBIN OC/VO
Here's a dog. Dogs, you know, run and jump, what do you have? One bone, two bones, little bones and then the digits, the equivalents of the fingers or toes. And, of course, here's a bird. Its limb has been modified into a wing, and it has one bone, two bones, lots of bones, and then digits. The amazing fact is, in each of these creatures, the skeletal architecture is largely the same as ours. And what was utterly surprising is that the skeleton of every animal walking the earth today has this fundamental pattern of one bone, two bones, little bones, fingers. Owen didn't know why creatures had that pattern. It was a mystery to him. It really took a new insight, an insight from Charles Darwin,

which basically said the reason why animals have this common pattern is because at some time, in the distant past, they all shared a common ancestor that had a version of this pattern too .

MUSIC IN

NEIL SHUBIN VO
According to Darwin, we should be able to trace the evolution of our limbs and hands by going back in time down our family tree. Starting with our primate ancestors, we see hands and limbs that look very similar to our own . Go back a bit further to the first mammals and we find deeper similarities in the paws. And we see how paws emerged from more distant relatives . And if we go back even further, we reach our most distant four-legged ancestors. These animals, the earliest tetrapods, were among the first to have Owen's "one bone, two bones, lots of bones" pattern. But when we enter the underwater world, around 400 million years ago, instead of animals with limbs, we find prehistoric fish with fins . And that brings us to a great mystery of biology. How did we get from fish with fins to animals with arms and legs? Darwin boldly predicted that there must have been ancient animals, transitional forms, that bridged this gap . But what would such an animal look like? Would it have limbs, or fins, or both ? Such a creature reflects a critical step in the origin of the human hand. I set out to find one.

MUSIC OUT

NEIL SHUBIN VO
I started my search back in the early '90s, when I worked in Philadelphia.

NEIL SHUBIN VO
Okay. I knew that finding this transitional fish was going to be a tall proposition.

TED DAESCHLER OC/VO
A lot of them around in the Chicago lab.

NEIL SHUBIN VO
And the first question was where to look. The world's a big place. The Earth is a giant planet…

NEIL SHUBIN OC
…and fossils are very small, so how do you find those things?

MUSIC IN

NEIL SHUBIN VO
Well there's a checklist we run through. We look for places in the world that have rocks of the right age. If you're interested in the origin of dinosaurs, there's one age of rock to look at. If you're interested in the origin of transitional creatures between water and land, there's another age of rock.

NEIL SHUBIN VO
Then you look for places in the world that have rocks of the right type. The kinds of rocks that are likely to hold fossils. We knew from previous discoveries that rocks from the Devonian era, around 360 million years old, were likely to contain early tetrapod fossils. And it turned out we had rocks of that age right here in Pennsylvania.

TED DAESCHLER VO
The other thing is that.

MUSIC OUT

NEIL SHUBIN VO
To look for good sites I teamed up with geologist, Ted Daeschler, and we've been fossil-hunting buddies ever since.

TED DAESCHLER OC/VO
You know what? We've tried it through here, even going down into West Virginia. We are sort of maybe an odd couple.

TED DAESCHLER OC
Neil is excitable and enthusiastic, which is wonderful. I'm enthusiastic as well but I think maybe not quite as vociferous.

TED DAESCHLER VO
I might tend to hunker down more and focus on recovering the material as we start to find it. And Neil might be a little bit more, "Okay, what's over the next horizon. What's over the next hill?"

TED DAESCHLER OC
Neil is on that edge, always thinking about the new place to go.

MUSIC IN

NEIL SHUBIN VO
Ted and I would sit in the car with maps in one hand, and geological papers in the other, and we tootled through these state roads, looking at the rocks, saying, "Okay, what kind of rock is this again? What kind of age is it?" But the problem in Pennsylvania is that it's not a desert. The bedrock is not exposed to the surface. You have forests. You have grass. Turns out the best exposures of rock in the state were made for us by the Pennsylvania Department of Transportation, because they would dynamite. They'd exposed sections of the geological record.

NEIL SHUBIN OC
And we eventually hit this one road cut…

NEIL SHUBIN VO
…a giant exposure. It's called Red Hill.

TED DAESCHLER VO
It probably is.

NEIL SHUBIN VO
Oh, my God. And then we knew…

NEIL SHUBIN OC
…okay, this was the place to hit.

MUSIC OUT

NEIL SHUBIN VO
We had ambitions to explore the globe. But our first expedition didn't take us to an exotic desert halfway around the world…

MUSIC IN

NEIL SHUBIN VO
…it happened by the side of a Pennsylvania highway. Ted revisited Red Hill one time when I was not there.

MUSIC OUT

NEIL SHUBIN VO
He made a phone call to me. He says, "Hey, Neil. I think I've found something really important." I said, "Well…

NEIL SHUBIN OC
…what did you find?" He's like, "I think I found a tetrapod." I said, "Ted, you kidding me? I mean, no. You're not going to find a tetrapod on your second or third trip to Red Hill. This gonna take years of work."

TED DAESCHLER VO/OC
So, I was moving along this layer and saw beautiful little fossil bone material, chipped around it a little bit, right, right on this layer, and lo and behold, uncovered what turned out to be a very significant specimen.

MUSIC IN

TED DAESCHLER VO/OC
This is the shoulder girdle of an early, limbed animal. It was a new species. It was a whole new kind of animal. And although we only have a shoulder girdle, it's actually a very informative part of the skeleton. It would be on the left side, the skull would go off in that direction, and the animal itself would be about a meter long. And just from the shoulder girdle we can learn things about how it may have…

TED DAESCHLER VO
…held that limb. And of course, it does compare to other animals that are similar from other parts of the world and we can use those to learn other aspects of Hynerpeton.

NEIL SHUBIN VO
These early four-legged animals belong to a group I like to call 'The Stegas.'

MUSIC OUT

MUSIC IN

NEIL SHUBIN VO
Some of the best specimens had been found in Greenland by a paleontologist named Jenny Clack, who began working there in the 80's.

JENNY A. CLACK VO
The idea of transition between animals with fins and animals with limbs…

JENNY A. CLACK OC
…has been thought about for a long time. But until recently there had only been three data points. Something was obviously a fish at one end; something that was obviously an animal with legs and walking around at the other end, and in the middle, was this very peculiar thing called Ichthyostega.

NEIL SHUBIN VO
Using the latest scanning techniques to build a 3D model of Ichthyostega, Jenny's trying get a better sense of how this creature lived . She's working with animal motion expert Stephanie Pierce at London's Royal Veterinary College .

MUSIC OUT

STEPHANIE PIERCE VO/OC
Basically what we wanted to see was how much movement was possible at each of the limb joints. And how this compared to modern animals.

NEIL SHUBIN VO
They compared Ichthyostega to modern tetrapods…

MUSIC IN

NEIL SHUBIN VO
…like salamanders, to figure out how this fossil might have moved. Using pressure pads and high-speed cameras, they could measure how the limbs of modern animals work and compare this to the bones of Ichthyostega.

JENNY CLACK VO
Ichthyostega's forelimbs could push…

MUSIC OUT

JENNY CLACK VO
…the top half of the body off the ground. But the back end has got these paddle-like hind limbs, which are useful in water for swimming with, but on land act as stabilizers to stop the thing toppling over.

MUSIC IN

NEIL SHUBIN VO
Anatomy of the bones suggested that this four-legged animal had just come onto land. It was right at the edge of our search . But between these tetrapods and ancient fish, there was still a gap spanning millions of years . If we could find an animal within that gap, we'd be filling in a crucial piece of evolutionary history.

MUSIC OUT

TED DAESCHLER OC
There it is.

NEIL SHUBIN OC/VO
Yeah. So now there was a new challenge, where on earth should we look next? I remember sitting in the office…

NEIL SHUBIN OC
…and we were doing the sort of usual banter one day about something geological.

MUSIC IN

NEIL SHUBIN VO

We had a college textbook and were just thumbing though the diagrams in the book and boom there was this figure that changed our lives.

TED DAESCHLER VO
There's the map.

NEIL SHUBIN VO
It was a map of North America, which highlighted three areas of Devonian rock of just the right type to hold fossil fish moving onto land . There were our Red Hill rocks in Pennsylvania…

TED DAESCHLER VO
Been there done that. Worked on those very rocks.

NEIL SHUBIN VO
Then there were rocks in Greenland, which Jenny Clack had already searched.

TED DAESCHLER VO/OC
But, it was that little.

NEIL SHUBIN VO
Finally, there was this strip across northern Canada and these rocks were ten million years older.

MUSIC OUT

NEIL SHUBIN OC/VO
I remember seeing that and saying to myself, "Holy cow. This is what we're looking for." My heart was racing when I saw that because no…

TED DAESCHLER OC
Yeah.

NEIL SHUBIN OC/VO
…paleontologist had worked on that expressly looking for early tetrapods. Then you dug out the aerial photos, and that's when I got kind of terrified. I remember seeing this…

TED DAESCHLER VO
I know.

NEIL SHUBIN VO/OC
…for the first time, thinking, "You got to be kidding me. You know, look at all this snow. How do you work there?"

MUSIC IN

NEIL SHUBIN VO
All right, so one, two, three, four, five, six, seven, eight.

MALE DISPATCHER VO
Okay, two-six is clear.

NEIL SHUBIN VO/OC

Back in 1999, when we embarked on our first Arctic adventure , we had little idea what we were in for, nor that we were starting a search that would last over a decade . Wow, that is a lot of snow. Here in the High Arctic of Canada, there are no human settlements for miles and miles. No roads and all you've got is what you bring with you . Here there's always the risk of being trapped by some of the worst weather on the planet . We're entering the valley now.

TED DAESCHLER VO
This is the big gate.

NEIL SHUBIN OC
Oh, there she is.

TED DAESCHLER VO
Yep.

NEIL SHUBIN VO
I'm looking right at the quarry. We had a narrow window during the month of July, when the snow melts just long enough to let us in.

MUSIC OUT

NEIL SHUBIN VO/OC
We were trained fossil hunters, but now we would have to figure out how to become Arctic explorers. So when the helicopter drops you off in the Arctic for the first time, you're standing here saying, "What am I doing here?" You know, you're thinking, "Oh, polar bears", that's the first thing you look for. Is there anything on the landscape? Everything white becomes a polar bear. The last thing on your mind are fossils.

MUSIC IN

NEIL SHUBIN VO/OC
It's hard to believe when you look out across this frozen terrain that once this was a warm, watery world swimming with life . Here we are in the Arctic and we have a snowstorm coming and, you know, we're looking at rocks behind us, but there's this huge disconnect between the present and the past. What we see today is valley with red and green rocks, that are tilted, stacked one on top of the other, but that's not how it was in the past. These valleys have been carved by glaciers that have moved back and forth. And those red and green rocks actually, at one point, extended across the valley and they were straight. They weren't tilted. Now look inside the rocks and what those rocks tell us that this valley, 375 million years ago, was a giant floodplain and that floodplain was filled with rivers that swelled their banks and sometimes shrunk, but in those conditions formed swamps and streams of all different sizes.

NEIL SHUBIN VO
And inside those streams was diverse life.

NEIL SHUBIN VO
Somewhere out there, we were hoping to find an intrepid fish on the brink of the historic transition to life on land.

MUSIC OUT

NEIL SHUBIN VO
Could we ever find evidence of this momentous event buried in sediments…

MUSIC IN

NEIL SHUBIN VO
…that had been crushed and distorted by 375 million years of geological upheaval ? When you think about everything that has to go right for a creature to be first to be a fossil and then a creature's fossil to be discovered by a paleontologist. It is like finding a needle in a haystack. We were determined to find that needle. If it was out there.

MUSIC OUT

MUSIC IN

NEIL SHUBIN VO
Back in Chicago, I had another way of tracing the anatomy…

NEIL SHUBIN VO
…we share with fish, using a different kind of window into our evolutionary history. When I wasn't looking for fossils in the summers, I'd spend my time looking under a microscope at embryos. And I was watching, at the time, bodies forming from egg to adult. And there is an incredible beauty to that process.

NEIL SHUBIN VO/OC
In the early stages of development all animals start as a single cell . They divide again and again until gradually a body emerges with a front, a back, a top and a bottom . It became very clear early on in the process some of the most important embryos were fish. Because fish have the basic body plan in their embryos that was to become our own bodies.

NEIL SHUBIN VO
If you see an early fish embryo and a human embryo side by side, you'll see something remarkable. They look almost identical. We really do look like fish. Both embryos have a head, a body, a tail and many other similar features.

NEIL SHUBIN OC
And one of those similarities exists in the neck or what's called the pharyngeal area.

NEIL SHUBIN VO
In both fish and people, what you find are a series of swellings called gill arches . Turns out that in fish, those swellings become components of the gill apparatus. In people, they become portions of our lower jaw, portions in our middle ear and part of our voice box. So this…

NEIL SHUBIN OC
…is a wonderfully elegant developmental process.

MUSIC OUT

NEIL SHUBIN OC
But sometimes things go wrong.

MUSIC IN

NEIL SHUBIN VO/OC
And when they do, your inner fish can come out. So my kids are really good friends with the Richardsons, one day I get an e-mail from Seth, their father, who says, "Doctor, my wife's a fish." And I said to myself, "I got to check this one out." We're here for the fish.

SETH RICHARDSON OC/VO
The fish is available. It's fresh. Come right through. I think if you go towards the back.

NEIL SHUBIN OC
Oh, we'll cut through, yeah. Hey Seth, is this your family album?

SETH RICHARDSON VO
Yes, exactly.

NEIL SHUBIN OC/VO
So you're a fish? Now first off, if you are, and you're more of a fish than I am…

MUSIC OUT

MOLLY RICHARDSON OC
Yes.

NEIL SHUBIN VO
…I'm very jealous. So prove it.

MOLLY RICHARDSON VO
All right. Well, here it is. There's my gill.

NEIL SHUBIN VO/OC
Right there. So what happens during development is we all have gill arches. We all develop them. This little pit is a leftover from an ancient gill. And I am incredibly jealous of you, Molly, because you are more of a fish than I am. We're all fish, but some are more fish than others.

MOLLY RICHARDSON VO/OC
That's right. Some just haven't evolved very far.

NEIL SHUBIN VO/OC
No, you're the lucky one. So what's really cool is when you know paleontology and developmental biology, many of the muscles and nerves and bones I'm using to talk to you with right now, and many of the muscles and nerves and bones you're using to hear me with right now, correspond to gill structures in fish. You know, and we see that in fossils, we see that in embryos, we see that in DNA, I mean, and we see that in you.

MOLLY RICHARDSON OC
My brother-in-law has webbed feet.

MUSIC IN

NEIL SHUBIN VO/OC
I love your family by the way. While features like fish gills have been retooled in our anatomy…

NEIL SHUBIN VO/OC
…other body parts perform the same job, but end up in different places. Like testicles. Well, we're here to see some gonads.

DIRK OC
Okay.

NEIL SHUBIN OC
Fish gonads.

MUSIC OUT

DIRK OC/VO
Oh. I'll just dissect this little guy here.

NEIL SHUBIN VO/OC
Yeah, if you could pop that bad boy, that would be.

DIRK OC/VO
Sure. Come right out of there.

NEIL SHUBIN VO
Right.

DIRK OC
Right there.

NEIL SHUBIN OC
Yeah, you know, so there you see, you know, there's the heart.

DIRK OC
Right.

NEIL SHUBIN VO
There's the liver, you know. The gonad is right there.

DIRK VO
Look at it.

NEIL SHUBIN VO
So you know what's funky about these things? Is the gonad is towards the chest, right near the heart. You know, but what's stunning is you and I, like every other mammal, you know, our gonads started up there and descended down to here.

DIRK OC
It might be better where they were. No. It's safer that way.

NEIL SHUBIN OC
Well, in some senses, they would.

MUSIC IN

NEIL SHUBIN VO

Having gonads close to the heart is fine for our cold-blooded fishy relatives, not so good for warm-blooded mammals . Sperm can't stand the heat, so that's why our testicles have to drop to a cooler place, outside the body. When a human embryo develops, the gonads start deep in the body, just like they do in fish, and then descend through the body wall, mirroring evolution. But that creates a weak spot in males where our guts can pop through. This leaves us vulnerable to certain kinds of hernias. You know, you think about why humans have hernias…

MUSIC OUT

DIRK OC
Okay.

NEIL SHUBIN OC
…it's because our testes descend…

DIRK OC
Right.

NEIL SHUBIN OC
And they start up here, they go down into the scrotum and the body wall gets weaker because of that reconfiguration.

DIRK OC
That passing of the testicles. Okay.

NEIL SHUBIN OC
Yeah. And so, you know, we'll find, you know, we'll find that you have a weakness in the body wall in some cases and folks get hernias.

DIRK OC
And that's why fish don't get hernias?

NEIL SHUBIN OC
That's why fish don't get hernias.

MUSIC IN

NEIL SHUBIN VO
Flaws in the human body, like our susceptibility to hernias, remind us that we're all adapted from ancient ancestors. We are, every one of us, just a jerry-rigged fish.

MUSIC OUT

NEIL SHUBIN VO
In July 2000…

MUSIC IN

NEIL SHUBIN VO/OC
…we were back in the Arctic for a second season, continuing the search for our elusive fossil. Now, we've actually found float bone on this level, so let's just stay close. We widened our explorations across the region, but we were

finding hardly anything, let alone the transitional fossil of our dreams. Then, just before we began to pull out, we were suddenly confronted with the real dangers of working in this wilderness. The team had separated into several different groups, we usually go out in pairs, because it's, you know, a dangerous place. One pair went down the valley, another…

NEIL SHUBIN OC
…went up the valley, you know, we spread apart for the day.

NEIL SHUBIN VO/OC
Two-six, two-six this is Bird Fjord. This is Bird Fjord, over. We all returned to camp at the end of the day and the idea is everybody needs to return back to camp by radio call. It's seven o'clock when we make our safety check back to the station. And so we're making dinner and we're waiting for the radio call, and you know kind of looking…

NEIL SHUBIN OC
…around, it's like, "Hey, you guys seen Jason?" "No, I ain't seen Jason. You seen Jason?" I said, "I asked you that question. You didn't see Jason?" And all of a sudden it became nobody saw Jason. Where's Jason?

NEIL SHUBIN VO
This is our youngest member, we were looking out for him the entire season, and no Jason.

NEIL SHUBIN OC
I mean, my heart was really beginning to race. Then I hear footsteps outside the tent, the tent fly opens, and there's Jason. His eyes are like globes, and he's like, "I found it. I found it." And I was like, "Jason, what did you find? Did you find a polar bear? What?"

NEIL SHUBIN VO
I mean every pocket was burgeoning with bones. He goes, "I got these…

NEIL SHUBIN OC
…bones." He's laying them out on the table, one after another.

NEIL SHUBIN VO
It's daylight 24 hours a day. So we ran down to Jason's site and began that night, to crawl it, looking for the layer that was kicking out the bones. As soon…

NEIL SHUBIN OC
…as we came to this bluff here and looked down…

MUSIC OUT

NEIL SHUBIN OC
…we saw why Jason was so excited, because beneath our feet were fossil fish bones, fragments of fossil fish, many of them, thousands of them. It wasn't just one fish, it was a whole aquarium. It was different species. It got better, because as we walked up the hill and we followed that carpet of fossil fragments, it stopped. Meaning it likely came from one layer. And if we had any luck at all we'd find that layer and see what's inside.

NEIL SHUBIN VO/OC
That's not. But there is this here though. It took several weeks, but we eventually located the layer of rock from which the fossil fragments were spilling , and then looked for telltale signs of bones protruding in the hope it might lead us to more complete specimens. You can see this tiniest little white fleck here… that told us stop, you know,

because that little white fleck shows the structure of a scale. And then you look carefully and it's clearly a scale on end. And once you see that scale on end…

MUSIC IN

NEIL SHUBIN VO/OC
…you see another piece of bone here. You see another piece of bone here. We're on the layer itself so it's a matter of stop. Now what we're going to do is remove this ice and rubble to expose the layer as a little platform. Only a person. To reach the buried fossils, we'd need to mine the rock face, but we were running out of time. All right, let's get that rock out of there. Once again, our short window of snow-free weather ended .

MALE DISPATCHER VO
Now, are you guys looking for that flight tomorrow? Or were you guys delaying it until the fourth?

NEIL SHUBIN VO
We're about three away.

MALE DISPATCHER VO
Okay. Roger that.

NEIL SHUBIN VO
We'd have to wait another summer to dig out our ancient riverbed.

MUSIC OUT

MUSIC IN

NEIL SHUBIN VO
Back home, a very different kind of scientific adventure was unfolding. A revolution was underway…

NEIL SHUBIN VO
…in evolutionary biology. One that would reveal a profound genetic connection between fins and limbs. My lab would play a role in the search, but we were part of a much bigger effort.

MUSIC OUT

NEIL SHUBIN VO
At the forefront of this quest was my colleague, Cliff Tabin, a geneticist at Harvard University.

MUSIC IN

NEIL SHUBIN VO
Cliff had been focusing on how digits, like fingers, form. And in his work, he relied on chick embryos. For biologists, chicken eggs offer a window into the process of development.

CLIFF TABIN OC
If you take a chick egg and cut a hole in the shell and throw it away…

CLIFF TABIN VO

…you can see the embryo floating on top of the yolk. It's right there. It's accessible. You can start to probe what's important for it to form by removing little bits and saying, "Does that disrupt the process?" Or by moving tissue from one place to another and say, "What does that do?"

NEIL SHUBIN VO
Cliff was following a long line of scientists using chickens to investigate how limbs develop.

NEIL SHUBIN VO
In the 1950s, John Saunders was one such scientist. Saunders and his team experimented on chick embryos just a few days old. They focused on little protrusions, called limb buds, from which the wings would eventually emerge. In one experiment, Saunders took a small patch of cells from one side of a bud and transplanted it to the opposite side to see what would happen. When he came back a week later, much to his surprise, he found that the chick embryo had grown a second set of digits, one a mirror image of the other. That tiny patch of cells was clearly special. Somehow it was telling the digits where to form.

CLIFF TABIN VO
The way that we now think of it is that those cells…

CLIFF TABIN OC
…instruct the rest of the limb by making a long-range signal, a beacon that they send out that the other cells see and respond to.

NEIL SHUBIN VO
The identity of that signal was a great mystery that went unsolved for decades.

NEIL SHUBIN VO
But Cliff had a hunch. He, and some colleagues, suspected that the signal might be a single molecule that came from a single gene.

NEIL SHUBIN VO/OC
He based his suspicions on research that was changing how we understand the role of genes in making body parts. It was work that had been done on an entirely different animal. It was a tiny little creature that's really small, that breeds very rapidly and that you can study in the laboratory. And it's this. The humble little fruit fly. By studying how fruit flies develop, scientists had made some amazing discoveries. Individual genes can do complex things, like guiding the formation of entire body parts. There was one gene, dubbed "hedgehog," that caught Cliff's attention. It stood out because it seemed to send out an organizing signal.

CLIFF TABIN VO
In a fly, this signal, hedgehog…

CLIFF TABIN OC
…told different cells to do things in a particular order depending on how close they were to the source of the signal.

NEIL SHUBIN VO
Cliff wondered if a gene like hedgehog might play a similar role in chickens. So his team took the fly hedgehog gene, and looked for a match in the chicken. After months of searching, they found it. Then, remarkably, they discovered the gene was active in exactly the same patch of cells identified by Saunders. They dubbed this new gene "Sonic Hedgehog," after the video game character. So did Sonic Hedgehog produce the mysterious signal everyone wanted to find?

CLIFF TABIN OC
Ultimately we wanted to know whether this gene that we discovered, Sonic Hedgehog, really is the key signal for making the array of digits in the hand.

NEIL SHUBIN VO
In a ground-breaking experiment, Cliff and his team added a bead containing pure Sonic Hedgehog to the wrong side of the growing limb bud, echoing Saunders' experiments. When he returned a week later, he found his chick had two sets of digits just like Saunders' chick. This was a major discovery. Sonic Hedgehog, a single gene, was the source of the signal responsible for generating the pattern of the digits.

CLIFF TABIN VO
And that really nails it.

MUSIC OUT

CLIFF TABIN OC
It really meant that we had the linchpin in our hands and could start looking at how that process worked in detail.

NEIL SHUBIN VO
It turns out Sonic Hedgehog shapes not just the wings of chickens, but the paws of mice and other animals, and even our own hands.

MUSIC IN

NEIL SHUBIN VO
If you want to see just how important Sonic Hedgehog is to us, meet the Hubbard family.

MUSIC OUT

NEIL SHUBIN OC/VO
Can I count your fingers? Let me see. I can count. I went to school, too.

KAMANI HUBBARD VO
One…

NEIL SHUBIN VO
Two…

KAMANI HUBBARD VO
…two…

NEIL SHUBIN VO
…three…

KAMANI HUBBARD VO
…three, four…

NEIL SHUBIN VO
…four, five…

KAMANI HUBBARD VO
…six.

NEIL SHUBIN VO
…and six is special.

MRS. HUBBARD VO
Yay.

NEIL SHUBIN OC/VO
Look at that hand. Kamani was born with an extra digit on each hand and foot. Grab my, squeeze my finger as hard as you can, let me see your grip. No harder than that. You can go way harder. Oh. Oh! Why this happens had long been a mystery. It turns out that people like Kamani often have mutations that alter the effect of their Sonic Hedgehog gene.

MR. HUBBARD OC/VO
With the condition in Kamani, I just want to know what's allowing him to be so different?

NEIL SHUBIN OC/VO
The way our arms and legs originally develop in the womb is they push out from the body as a little bud. So we have four little buds sticking out of us as we're little embryos. Then those buds grow out…

MUSIC IN

NEIL SHUBIN OC/VO
…and eventually they grow out and they elongate. What you have is a paddle, a big broad paddle.

NEIL SHUBIN VO
Just as in the chicken limb, Sonic Hedgehog sends out a signal to shape the pattern of our digits. When it's strong, a pinky forms. And as it weakens, one by one, different fingers are made until we end up with five. If we turn down Sonic Hedgehog, fewer fingers are made. But if we were to increase the effect of Sonic Hedgehog we would get extra fingers, like Kamani's.

CLIFF TABIN VO
It is really quite beautiful…

CLIFF TABIN OC
…that something as simple as a single signal moving through the limb could have such profound and differential effect on digits.

NEIL SHUBIN VO
We now knew that Sonic Hedgehog played a powerful role in shaping the limbs of all sorts of four-legged animals.

NEIL SHUBIN VO
So how far back did it go? Could it be a legacy passed down from the earliest fish?

MUSIC OUT

NEIL SHUBIN VO

Back in my lab, that was a question my post-doc, Randy Dahn, was tackling.

MUSIC IN

NEIL SHUBIN VO
Randy was investigating an ancient type of fish, skates, whose embryos grow in a sac called a “mermaid’s purse.”

RANDY DAHN VO
I guess the thing that struck me the most when I first opened the skate egg was how shockingly similar…

MUSIC OUT

RANDY DAHN VO
…that embryo looks to a chicken embryo, a mouse embryo, a human embryo.

RANDY DAHN OC
As an embryologist, I should have understood, of course they’re going to look similar, but still when you see that you’re thinking…

RANDY DAHN VO
…there’s 400 million years of evolution that separates me from that embryo and at…

RANDY DAHN OC
…one stage in my life…

MUSIC IN

RANDY DAHN OC
…that was exactly what I looked like.

NEIL SHUBIN VO
It’s clear we have a shared genetic history with fish, but do the genes that shape our hands also shape these skate fins? To find out, Randy manipulated the skate embryos like Cliff had done with the chick embryos . He put a bead containing the Sonic Hedgehog molecule on the opposite side of a growing fin bud.

RANDY DAHN VO
And it turns out that…

RANDY DAHN OC
…Sonic Hedgehog was sufficient to cause a mirror image duplication, a second fin, to form in the skate.

NEIL SHUBIN VO
This is exactly what Sonic Hedgehog had done in Cliff’s chickens.

RANDY DAHN VO
We were absolutely stunned. And you have to remember that this is a skate embryo and what that tells us is that…

RANDY DAHN OC
…these very basic patterning mechanisms are performing the exact same functions…

MUSIC OUT

RANDY DAHN OC
…in the skate, in the shark, in the chicken, in the mouse, all the way up to humans.

MUSIC IN

NEIL SHUBIN VO
We had traced Sonic Hedgehog all the way back to life in ancient oceans . A gene that determines the shape of our hands was also shaping the fins of some of our most distant fish relatives . Our inner fish runs deep.

MUSIC OUT

NEIL SHUBIN VO
But there was still a big mystery to solve.

MUSIC IN

NEIL SHUBIN VO/OC
How did our fish ancestors make the transition onto land? And what did they look like? We were still looking for our elusive fossil, frozen forever on the brink of this great transition. Each summer, we returned to Jason's ancient riverbed to continue excavating. We needed to move lots of rock, to expose the narrow seam containing the fossils . But then, we'd switch to brushes and dental picks to uncover the delicate fossilized bone. It's just this incredibly funny paradox. You know, we're in this huge landscape and we're always cramped together. You know, our, my head's next to Ted's feet. Mark's head's next to my feet. It's this tiny little spot. It was in such a tiny corner of this vast landscape that we finally struck gold.

NEIL SHUBIN VO
Well, it was the second week of July, in 2004, we were all working in series in this hole. And Steve says "Hey, guys, what's this?" Ted and I go running over…

NEIL SHUBIN OC/VO
…and what we saw, was this "V" here, it was covered with rock. And as soon as we saw this "V" and we saw these teeth under it, it became very clear that this little "V" we're seeing is the tip of a snout and that this was a snout of a flat-headed fish. We stopped in our tracks. A flat head was a likely sign of a transitional fish . Here was the snout of exactly the creature we were looking for and it was sticking out of the rocks. So if we had any luck whatsoever, the rest of the creature would be, you know, encased in the rock. So we dug all the way around the fossil, leaving a chunk of rock that we then encased in plaster . We couldn't wait to see what was inside. Okay, we get home.

MUSIC OUT

NEIL SHUBIN OC
We knew we had a flat-headed fish, but how much of it did we have? Well, then the preparators had to take over. They removed the plaster jackets…

MUSIC IN

NEIL SHUBIN OC/VO
…and the first thing they did was to etch away at the rock, exposing the front part of the snout. Then about a month and a half goes by, and they start to find the orbits, the eye holes, and then we see the shoulder, and then we see the

fins, and then we see more and more and more and more until we see pretty much the entire topside of the body. What's really wonderful about this specimen is that we have the head connected to a body, and the body is connected to the fins, so we know that this fin comes from this animal, and we know its size and how it fits together.

NEIL SHUBIN VO
Later, we found parts of other specimens . And some of these were really big, up to nine feet long . The local Inuit people named our fossil "Tiktaalik," which means "large freshwater fish." And as we took stock of our discovery, the real excitement began. Here was an animal Darwin had predicted, a real anatomical mixture. It had some features of fish, like scales and fins and gills. It also had lungs for breathing air. And, to our astonishment, it had a neck, the earliest one like ours ever found . But inside the fins lie the clincher. We see an early version of Owen's one bone, two bones, lots of bones pattern that we see in our own limbs today. It even had a kind of wrist, the first signs of a link to the human hand . Every time you flex your wrist or shake your head you can thank Tiktaalik and its Devonian cousins adapting to life in these ancient streams.

NEIL SHUBIN VO
Unlike other fish, Tiktaalik could use its neck to watch out for predators and to hunt smaller prey . And because those fins were strong enough to lift its body out of the water, a whole new frontier opened . Over millions of years, the two pairs of fins in fish-like Tiktaalik would lead to the two pairs of limbs in every bony animal on earth . It's a powerful legacy we can see in our own arms and legs today.

MUSIC OUT

NEIL SHUBIN OC/VO
Well, to think about Tiktaalik, think about this, think about a push-up. What are we doing when we do a push-up? We're using the muscles that attach to our chest, and attach to the underside of our arm to give us the power to raise up; we use our elbows, and use flexion at the wrist, which is very important because it allows our palm to contact the ground. Here's the fin of Tiktaalik. And what does it have? It has a massive surface for a connection of muscles that would attach the shoulder to the underside of the upper arm. It has evidence of a highly mobile elbow, and it even has a wrist that can flex so that the equivalent of the palm can contact the ground. Here's a fish that can do a push-up.

MUSIC IN

NEIL SHUBIN OC
I remember looking at the wrist of Tiktaalik for the first time, and at that moment I felt akin to what I felt in the anatomy lab…

NEIL SHUBIN VO
…when I saw the cadaver and its hand. The hand actually defines us in many ways.

NEIL SHUBIN VO
When you think about what makes our species unique and special, it's having thoughts and being able to make those thoughts real. And the way our thoughts become real is through use of our hands – to build things, to make things. Yet the basic form of this wonderfully complex, quintessentially human piece of anatomy can be traced back to the fins of ancient fish . It's an incredible evolutionary story that we can now unravel.

NEIL SHUBIN VO
When Tiktaalik was first conceived, like every animal that has ever lived, it started as a single cell, which slowly formed into a body. Small buds appeared and genes, like Sonic Hedgehog, shaped them into fins. Over millions of years, fins like these evolved into a myriad of forms. Like the limb of this early amphibian with eight fingers. As

millions more years passed, new variations emerged. From the clawed limbs of reptiles that would colonize dry land. To the powerful arms of primates that could traverse through the trees. Until eventually a remarkable piece of anatomy arose that would itself transform the world, the human hand. This history is not just in our bone, flesh and muscle; it's in our DNA. And that's what connects us all the way back to our inner fish. Fundamental portions of our own bodies…

NEIL SHUBIN OC
…originally came about in fish living in water, and the great transition from life in water to life on land set the stage for a whole new set of anatomical inventions that were themselves to form the core for our own humanity.

MUSIC OUT