MUSIC IN

NEIL SHUBIN VO/OC
From the plains of South Africa to the shores of Nova Scotia. In the bones of ancient creatures. You have a skull right in this block. And deep inside your DNA lies an incredible story. The story of your body and why you're built the way you are. Your skin and hair. Your complex teeth and remarkable sense of hearing can all be traced back to ancient reptiles that once ruled the Earth. Their bodies were shaped by great transitions in the history of life. And that legacy still shapes our bodies today. My name is Neil Shubin. As an anatomist I look at human bodies differently from most people. Within us I see the ghosts of animals past. Distant ancestors who shaped our anatomy in surprising ways. Prepare yourself for a trip back to an ancient world. If you really want to know why you look the way you do, it's time to meet Your Inner Reptile.

MUSIC OUT

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NEIL SHUBIN VO/OC
It was here in the small town of Parrsboro in Nova Scotia, over 25 years ago, that I first discovered my inner reptile. Oh my Gosh. This was my second home when I was in graduate school. This little Main Street, I can't tell you how many times I ripped back and forth. A lot of my personal history is on this street. Back then I was a young, eager, Harvard graduate student off to lead my very first fossil expedition. Yeah there's the bay, isn't it beautiful? We're catching it at a really nice tide. What makes the Bay of Fundy a special place to hunt for fossils is its huge tides. They're the largest in the world. In just six hours 100 billion tons of water drains half a mile out to sea. These massive tides constantly erode the cliff face making it a wonderful place for exposing new fossils.

MUSIC OUT

NEIL SHUBIN VO/OC
You know we came to Nova Scotia to look at these orange rocks. And these orange rocks are kind of perfect. You have ancient lake beds. You have ancient streams. You have even a margin of an ancient desert all in one small place. And so this area we hit really hard. We had our eyes to the rocks. We had our collecting bags and our rock hammers and we were ready to fill them with bones. The challenge is we didn't fill them with bones. We didn't find much of anything. And really our luck was to change because of events in town.

MUSIC IN

NEIL SHUBIN OC/VO
So the breakthrough came when the president of the local Lions Club invited us to be judges for the town's beauty contest. So it was up to us to perform this onerous task. The problem was in judging the contest and in the celebration afterwards we stayed up way too late in the evening. And that late night revelry had consequences the next day .

NEIL SHUBIN VO/OC
So the next morning we got up too late. It was high tide. And the tides are just so huge here, what happens is, the tide will lap up against the rocks. And what we found is we were stuck. We were surrounded by dark volcanic rocks formed from hot lava flows. Nobody in their right mind would look for fossils here. It was a beautiful day so we, you know, we skipped rocks. Rocks weren't the best in the world for skipping. My buddy Bill had disappeared. Then I heard his voice. He's like Neil, you may want to come over here and take a look at this. I'll never forget those words as

long as I live. Holy cow, this is the spot. I mean it's, it jutted out more. That was 1985. Well what happened was, Bill was at this point and what he had discovered was that inside these basalt boulders lie seams of this brown sandstone. And within this brown sandstone were bones. As we chipped away at the rock we uncovered countless fossils. There were leg bones, teeth, even whole jaws. This site yielded thousands of pieces of bone from a momentous period in our history. We found loads of things. But the real gem is in here. What you're seeing here is an upper jaw. There's a canine tooth. A series of other smaller tooth behind it. These 200 million year old teeth belonged to a creature called a Tritheledont. It may look like an insignificant little animal, but it's unlike anything alive today. Now what we have here is really a unique kind of animal with a unique mix of features. Part reptile, part mammal. We see it in its skull, in its jaws, in its limb bones, virtually every feature of its anatomy. This is a creature right on the cusp of the transition from reptile to mammal. A key moment in the evolution of the human body.

NEIL SHUBIN VO
Trace your ancestry way back in time and you'll find an ancient relative. A fish-like creature that crawled from the water onto land about 375 million years ago. Animals like this gave rise to amphibians, and more important to our story, reptiles. Over time one line of reptiles gave rise to early mammals. And eventually to us. But before you get the idea this was one smooth ride, your reptilian ancestors faced a rocky road. They would colonize a hostile land. Compete for food and territory. And even deal with the worst mass extinction the world had ever seen.

NEIL SHUBIN VO
Our lives today seem worlds away from this story. But every chapter shaped our reptilian ancestors, changing their bodies. And we can still see those features in our bodies today. One of the most surprising is visible in the first few weeks after conception.

MUSIC OUT

NEIL SHUBIN VO/OC
We've come to an IVF clinic to see our inner reptile. And Sapna and Dev have graciously allowed us to see their eight week old fetus and what's going on inside.

CLINICIAN OC/VO
Let's shrink the image a little bit. Oh well look at here. Here's two.

NEIL SHUBIN VO
Wow.

CLINICIAN VO/OC
We have twins.

MUSIC IN

SAPNA OC
Did I tell you our life's about to change?

NEIL SHUBIN VO
In the first few weeks of pregnancy, it's almost as if the embryo is a window back in time that reveals our evolutionary history.

CLINICIAN VO
This is the head. This is the heart and this is the tail.

MUSIC OUT

CLINICIAN VO
And here's the yolk sack.

NEIL SHUBIN VO
Oh, let's see. Oh wow, there you go. Yeah, you don't think about yolk in a human right? You think of yolk for chicken eggs.

CLINICIAN VO
Chicken eggs.

DEV VO/OC
Is that extra-large or jumbo?

SAPNA OC/VO
It's organic, free-range.

NEIL SHUBIN OC
Free-range, exactly.

MUSIC IN

NEIL SHUBIN VO
When you think of yolk you don't think of humans. But we have a little yolk sac in early development that gets smaller and smaller as the embryo develops. There's no yolk inside, it's a remnant from a time when our ancestors laid eggs. And that's not the only gift they left us.

CLINICIAN VO
This little bright white line around is the amnion. And then the black around the baby is the amniotic fluid.

NEIL SHUBIN VO/OC
The Amnion forms a fluid filled sac that cushions the embryo. When a mother's waters break this is the sac that bursts. That little tissue represents something that happened hundreds of millions of years ago and our connection to one of the great events in the history of life.

MUSIC OUT

MUSIC IN

NEIL SHUBIN VO
375 million years ago life took a critical turn. For most of evolutionary history our ancestors needed to live in water. It's where they fed, mated and most importantly laid their eggs. But when the first vertebrates ventured out onto land into a completely alien world, they faced a life and death challenge. How to prevent their eggs from drying out. Amphibians got around the problem by returning to water to lay their eggs. Reptiles evolved a far more radical solution. A whole new type of egg. They enclosed their embryos in a sac filled with fluid, the amnion. And then covered it with a protective shell. This meant they could lay their eggs on shore and start to invade the land. This innovation opened the floodgates for totally new kinds of animals. From snakes and birds to crocodiles and turtles. And eventually mammals like us. That egg laying history shows up in more than just our anatomy, it's also written in our genes.

MUSIC OUT

NEIL SHUBIN VO/OC
What's really amazing about genes is you can look at their changes. That is you can compare the genome of a human to the genome of a reptile to the genome of a chicken. And you can ask the question, how are they similar and how are they different? And that's exactly what researchers did.

MUSIC IN

NEIL SHUBIN VO/OC
They searched for a particular kind of gene that produces yolk in the egg. Reptiles and birds have several of these yolk genes that produce gobs of yolk protein to feed the embryo. Guess what? When researchers looked at humans, what did they find? They found we too have yolk genes but they're not longer functional. They're knocked out. They're derelicts. That's because long ago our ancestors stopped relying on yolk to nourish their embryos. The yolk genes began to decay until eventually they produced no yolk at all. But those broken genes still lie buried in our genome like fossils from the past. So what the genes tell us, what DNA tells us is that we have come from an egg-laying animal.

MUSIC OUT

NEIL SHUBIN OC
We're related to egg layers. We're related to reptiles. We carry the genetic signature of our eggy past inside of us.

MUSIC IN

NEIL SHUBIN VO
Not all our reptilian past is buried so deep inside of us. If you go to the beach, there's ample evidence all around you. Our skin can also be traced back to when our ancestors left the water. To combat the dry air on land they evolved a new kind of skin. They built up layer upon layer of dead cells to form a watertight barrier around their bodies. And you can see these layers most clearly when a snake sheds its skin. We have inherited those same dead skin layers to keep our bodies from drying out. But unlike reptiles, our skin is filled with its own moisturizers. Special glands that secrete oils to keep the surface layer hydrated. That's why our skin is soft and supple to the touch, while a reptile's is dry. So our skin arose from an ancient battle against the elements over 300 million years ago. But once our reptile ancestors had broken their ties to water, a new challenge lay ahead.

NEIL SHUBIN VO
The coastline of South Africa is one of the most dramatic landscapes on the planet. But to fossil hunters the real drama lies inside the rocks. They're home to one of the richest reptilian bone yards on the planet. On the other side of these mountains you'll find a desolate landscape stretching for thousands of miles. It's called the Karoo, the land of great thirst. And it holds clues to the evolution of some important parts of our bodies.

MUSIC OUT

NEIL SHUBIN VO
One of the region's best fossil hunters is an old friend of mine, Roger Smith. You remember the mid-'90s when we ran into you guys in Namibia?

ROGER SMITH VO
Yeah.

NEIL SHUBIN VO/OC
That place had thorns like I'd never seen in my entire life. I mean I gave so much blood that season.

ROGER SMITH OC
Once hooked into your flesh there's only one way to go and that's backwards.

MUSIC IN

NEIL SHUBIN VO/OC
The thing about Roger is he loves this place. You can't be with him, you know, for more than five minutes until you realize he lives, eats, sleeps, drinks these rocks. And it's a passion that just is so infectious. For Roger, this dusty bush holds evidence of an arms race between predators and prey. Pieces of bone that reveal an escalating struggle among our ancestors as they fought for food and territory on dry land. I was really excited to come here. I mean, I've studied about this place you know for much of my career, for decades. My expectations were this vast desert, you know, with beautiful exposures of rock. You know, so when I first came on this place I was kind of disappointed. And I see these grasslands. I didn't see a whole lot of rock. It was not what I expected.

NEIL SHUBIN VO
To the untrained eye, we could have been walking over a pile of rubble. But look closer and you begin to see evidence of life in these rocks.

ROGER SMITH OC/VO
It's the back end of a skull, yeah. But that's where the nerve cord goes through, come down the spine.

NEIL SHUBIN VO
And then this would be the front of the skull?

ROGER SMITH VO
That's right. Yeah.

NEIL SHUBIN VO
So the top of the head?

ROGER SMITH VO
Yeah.

NEIL SHUBIN VO
And then the snout would just dive down?

ROGER SMITH VO
Yeah.

NEIL SHUBIN OC
Wow!

You have a skull right in this block.

ROGER SMITH VO
That's right.

NEIL SHUBIN
The creatures that lived here were very different from anything alive today. They looked like reptiles. But they also had some mammalian features. So when paleontologists first found these fossils they named them the mammal-like reptiles. And the Karoo is covered with their remains.

MUSIC OUT

NEIL SHUBIN VO/OC
I mean over 50 feet here, we're stumbling over you know skeleton after skeleton of, you know, mammal-like reptile. I've never experienced that in my entire career. It was, it was a stunning morning.

MUSIC IN

NEIL SHUBIN VO
The fossils found here reveal key changes happening in the bodies of mammal-like reptiles.

SCIENTIST VO/OC
It almost looks like a tibia or fibula, maybe from the other side.

NEIL SHUBIN VO
Among the most telling for our story, were changes happening inside their mouths. Beautiful cusps. Oh you see them nicely on this side. Yeah.

ROGER SMITH VO
Look at that.

NEIL SHUBIN VO
And that takes us to one of my favorite topics: teeth.

NEIL SHUBIN VO/OC
For anatomists, teeth can reveal a lot about an animal's life. One of the great anatomists of all time was Baron Georges Cuvier, who lived in Paris in the 1800s. He was remarkably important, remarkably smart and remarkably arrogant. He had a boast, and his boast was show me the tooth of any animal and I can reconstruct its entire skeleton.

MUSIC OUT

NEIL SHUBIN OC/VO
Turns out Cuvier was pretty much right. Now here's a tooth. This is a huge tooth. Clearly came from a big animal. Flat surface on top. That animal clearly chews plant material. What is a big animal that eats plants? An elephant. Here's another one. Large canines, big scissor-like teeth in the back. This creature clearly, you know, is built to eat meat. This is a lion. So teeth contain so many answers to the basic biology of creatures. They can tell us what animals eat, what they likely looked like. But they can do so much more. They can answer mysteries that Cuvier could only have dreamed of knowing.

MUSIC IN

NEIL SHUBIN VO
Teeth give us a window into our distant past by telling us how our ancestors lived and evolved. Roger wants to show me a particularly striking specimen that's over 250 million years old. Oh wow, look at that. Ferocious. Look at those teeth.

ROGER SMITH VO
Now, this is a Gorgonopsid. These are the carnivores of that time.

NEIL SHUBIN VO
Boy the teeth really tell a story on that one.

ROGER SMITH VO
They certainly do, yeah.

NEIL SHUBIN VO/OC
Gorgonopsids might look a bit like T-rex but they lived millions of years before any dinosaur was around. This is a fossil that when you see it, you know exactly how it lived, what it did, you know. This wasn't messing around this creature.

ROGER SMITH VO
Absolutely, yeah.

NEIL SHUBIN VO
Gorgonopsids were ferocious predators with mouths full of highly specialized teeth. And that represents a dramatic change from the much more basic teeth of reptiles. Most reptiles have sharp peg-shaped teeth that all look really similar. These teeth are only great for one thing, biting. They can't strip or chew their food. Instead they tear off chunks and then swallow them whole. The gorgonopsids' teeth had come a long way from their reptilian cousins.

ROGER SMITH VO
Compared to the reptiles before it, there was no differentiation of incisors and canines. But this elongation of the canine is particularly a mammal-like feature. And their front teeth were like little needles that came together. Very, very well adapted for flesh tearing.

NEIL SHUBIN OC/VO
So here you start to see differentiation along the tooth row. They're all sort of the same shape, but they're different sizes, specialized in different ways. Gorgonopsids had virtual Swiss Army knives of teeth. Giant canines for piercing tough skin. And incisors for stripping flesh off a carcass. So they could avoid swallowing whole bones. Never before had such menacingly efficient eating machines ruled the land.

ROGER SMITH VO/OC
These particular Gorgonopsians were fairly long legged and the front legs were slightly sprawled. The back legs were nice and upright. So even in their gate they're somewhat between a reptile and a mammal.

NEIL SHUBIN VO
Over millions of years back teeth would also become more specialized. They developed extra ridges called cusps for chewing food. Allowing more efficient digestion and more energy for chasing prey. These ancient innovations were the precursors to the molars we have in our mouths today.

NEIL SHUBIN OC/VO
Without a mouth of molars, couldn't eat the apple. Without the incisors I couldn't eat the, whatever you call this. It's good by the way.

ROGER SMITH VO
Guava roll.

NEIL SHUBIN OC
Guava roll. Thank you for having molars, because I'm glad I can chew this one. You know but the humble tooth is very important for our lives today. Every time you bite into an apple, alright, that is a very complex behavior. Our front of our teeth, the incisors, bite into that apple. And they do so in almost a perfect way. The teeth occlude in a very fixed pattern, in a very precise pattern. We take for granted how we rely on precise tooth to tooth occlusion. Except when things go wrong. Except when we crack a tooth or something like that.

DR. MCDONNELL VO
Good look at you Neil.

MUSIC OUT

DR. MCDONNELL VO
And make sure everything is where it's supposed to be. And there's nothing in here that isn't supposed to be.

NEIL SHUBIN VO/OC
Wonderfully complex teeth might allow us to have a great bite, but it's come at a price. You know, one of the things that's interesting to think about is, you know, the consequences of the reptile-mammal transition are the fact that we need dentists.

DR. MCDONNELL OC
Thank you.

NEIL SHUBIN OC
It's really true. Yeah, right, thanks, thank you South African fossils.

DR. MCDONNELL OC
That's right. Thank you very much.

NEIL SHUBIN VO/OC
I mean reptiles don't need dentists, right? Because they're producing lots of teeth throughout their lives, you know. Boom, boom, boom, they produce them, they're out of there.

MUSIC IN

NEIL SHUBIN VO
Most reptiles, like this snake, grow multiple sets of teeth in their lifetime. There's a constant stream of new teeth erupting in their mouths. But after we lose our baby teeth we're left with one adult set to last us the rest of our lives. This may not seem like the best of strategies but there is a plus side. It allows us to develop our very precise bite.

MUSIC OUT

NEIL SHUBIN VO/OC
If you're continually replacing your teeth, right, I mean I think it would be hard to get that, you know, micron scale occlusion, which is so really important to us.

DR. MCDONNELL VO/OC
You're right. When we lose a tooth the changes that occur to compensate for the loss of that tooth and the space that it held…

MUSIC IN

DR. MCDONNELL OC/VO
…has a profound effect on our occlusions.

NEIL SHUBIN VO
The reason our rows of teeth match up so precisely is that our ancestors reduced the number of sets that they produced. We've made up for that by strengthening our teeth with extra roots and thick enamel to help them last a lifetime. Along with a little help from our dentists.

DR. MCDONNELL VO
That's neat. I'll have to take better look when I go to the zoo.

MUSIC OUT

NEIL SHUBIN OC
The zoo.

DR. MCDONNELL OC
With my kids. The reptile house is not my favorite place.

NEIL SHUBIN VO
Yeah, it's not great.

DR. MCDONNELL OC
I would like them in the form you find them.

NEIL SHUBIN VO
Dead?

DR. MCDONNELL OC
Yeah, dead 200 million years.

MUSIC IN

NEIL SHUBIN VO
For my dentist, Roger's tales from the Karoo would be the stuff of nightmares. But, for Roger what happened here is an endlessly fascinating drama. To him, the rocks and fossils tell the story of a vanished world.

ROGER SMITH VO
These rocks were laid down by large Mississippi-sized meandering rivers that flowed pretty much throughout the year.

NEIL SHUBIN VO
Long ago, this landscape looked dramatically different. It was wet, humid, with huge lumbering animals crowding the river banks.

ROGER SMITH VO
And these large Alsatian sized carnivores, the Gorgonopsids, which fed upon them. So they were flourishing.

NEIL SHUBIN VO
For nearly 20 million years the Gorgonopsids sliced and diced their way across the planet. But their reign of terror was about to end. 252 million years ago, the climate began to change dramatically. This cataclysm wiped out most animal species, including the Gorgonopsids.

ROGER SMITH VO/OC
As we go up here we start to see the change in the rocks from these wet floodplains to the drying out.

NEIL SHUBIN VO
Plants died, soils washed away. The Karoo became a dead zone.

ROGER SMITH VO/OC
This is the great end Permian mass extinction, the Great Dying.

NEIL SHUBIN OC
The mother of all mass extinctions as they say?

ROGER SMITH VO/OC
That's right, the mother of all mass extinctions.

NEIL SHUBIN VO/OC
You know, when you think about the history of life on Earth. If you lay out every fossil that we've ever discovered, there's certain periods of time where many creatures just disappear, never to be seen again and we call these, you know, the mass extinctions. Well, these mass extinctions are hugely important for understanding our world today. Understanding our bodies, how they came into being. Because these mass extinctions don't only just remove creatures, but they create new opportunities for the survivors.

NEIL SHUBIN VO
Not all our distant relatives were wiped out by the Permian extinction. The fossil evidence tells us that some survived on the surface, and others burrowed underground.

ROGER SMITH OC/VO
Neil, have a look at this. We're excavating an underground burrow. This was originally a hole down into the ancient floodplain, dug by one of these animals.

MUSIC OUT

ROGER SMITH VO/OC
And has been filled with sand and the sand is solidified now. And it's what we call a burrow cast.

NEIL SHUBIN VO/OC
This is so cool. When you look at this thing it's sort of an S shaped curve. But there's a branch going off of it. What's going on with the other shape?

ROGER SMITH VO/OC
Well, that's the entrance chamber and we know from some of our modern burrowing animals that these side chambers are used as latrines or places to store their waste.

NEIL SHUBIN OC/VO
Very sanitary of them. I'm impressed.

MUSIC IN

NEIL SHUBIN VO
Roger thinks that living underground may have helped our ancestors survive in a world of extreme temperatures. And it's within burrows like this that a new body feature may have emerged. One that is important to all mammals today: hair. Hair rarely fossilizes, but Roger sees tantalizing evidence in these ancient burrowers that may explain how and why it first evolved. Oh, that is beautiful.

MUSIC OUT

ROGER SMITH VO
Yeah.

NEIL SHUBIN VO
Two specimens?

ROGER SMITH OC/VO
That's two thrinaxodon, two juvenile thrinaxodon.

NEIL SHUBIN VO/OC
Wow. That is just absolutely beautiful. Do you know how lucky you are to find things like this? This is great.

ROGER SMITH VO/OC
Yeah, it was quite a sensation to find that. The way they're aligned, this body beautifully curled around, this one lying straight. It really looks like the burrow has collapsed on these and just preserved them as they were sleeping or hibernating.

NEIL SHUBIN VO
So, what do you know about the biology of these creatures just from what we're seeing here, the skeletons?

ROGER SMITH VO/OC
Its teeth clearly show that it had an insectivorous diet, beetles, cockroaches that sort of thing. It has large eyes, so it appears to have been nocturnal or at least in the dawn and dusk where they would come out of their burrows to hunt insects.

NEIL SHUBIN VO
Hair? That's the million dollar question. Does thrinaxodon have hair?

ROGER SMITH VO/OC
We prefer not to reconstruct thrinaxodon with full body hair. But, we do have evidence around the cheeks of whiskers, around the lower jaw as well as on their maxilla, around here, so more as a sensory organ than a thermoregulation.

MUSIC IN

NEIL SHUBIN VO/OC

These pits on the skull suggest that thrinaxodon had whiskers, just like a cat or a dog today. And, although we can't be completely certain, there's no evidence that it had hair anywhere else. So a hairless guy with whiskers at the front.

ROGER SMITH OC/VO
That's right, yeah. Very much a half and half animal.

NEIL SHUBIN VO
If we could go back in time and venture deep underground, we'd see that hair may have first evolved as a sensory organ. Whiskers would have helped thrinaxodon to navigate inside its burrow. And when it emerged at dusk, they were used to find its way in the dark. It's thought that over millions of years our distant relatives got hairier and hairier. And by 50 million years after thrinaxodon, they had started using hair for a new purpose, to keep warm.

NEIL SHUBIN VO
So hair dates back to a whiskered creature that lived in the aftermath of a great extinction. Complex teeth are linked to predators that battled in long lost lands. And a waterproof skin to a time when our ancestors moved onto land. Each of these body features is linked to a new chapter in the history of life. But hair, teeth and skin share an even deeper connection. One that lies at the heart of our inner reptile.

MUSIC IN

NEIL SHUBIN VO
There's a scientist in London, named Abigail Tucker, who's deciphering this ancient history.

ABIGAIL TUCKER VO/OC
This is SpongeBob the bearded dragon. And even though we look so different from our reptile friends here, we actually share lots of common features in our skin.

NEIL SHUBIN VO
Skin is not just an outer covering. Out of it grow body parts as different as hair, teeth, claws and scales. Abigail's passion lies in probing the mystery of how these so-called skin organs form. As an example, take the tooth. From a mouse embryo she cuts out an area of skin tissue from the lower jaw, which will eventually transform into a tooth. You need really steady hands for this kind of work.

ABIGAIL TUCKER VO/OC
Here I'm using a tungsten needle, but for very small tissue we glue an eyelash to a glass stick and use that as a really fine, little knife. It's starting to go now. There we go. So here we're looking at a tooth at the bud stage. It hasn't really sort of got a tooth shape yet, so it was a flat sheet and now it's pushed its way in, forming this little bud shape.

NEIL SHUBIN VO
After placing the tooth bud in an incubator Abigail can observe how it grows. And what she sees is remarkable. The skin folds in upon itself, very much like watching origami.

ABIGAIL TUCKER VO/OC
And now you really can see that that's formed a tooth and it's not just any old tooth. It's a molar tooth, with all these nice cusps developing here.

NEIL SHUBIN VO
And the tooth is just the beginning. All our skin organs, from hairs to glands are formed in a similar way. From simple folds in skin tissue.

ABIGAIL TUCKER VO/OC
We think that this is a really sort of ancient principle. It's this sort of folding that was one of the first steps to be able to actually then go on and form a very simple skin to something with lots of different organs developing within it.

NEIL SHUBIN VO
Once the process of folding skin was in place it could be modified to produce all kinds of skin organs. From a reptile's scale to a bird's feather and even that defining body feature of mammals, mammary glands. And what's surprising is the formation of all skin organs is controlled by a single master gene called EDA.

ABIGAIL TUCKER VO/OC
EDA we know is very important for doing things like controlling how hairy you are. Therefore, how many hairs you form in a particular area. Or, how many teeth you have and what are those teeth are going to look like. It seems to be doing something slightly different in all those different organs, but it's absolutely essential in all of them.

NEIL SHUBIN VO/OC
This gene plays a crucial role in building all the vital structures that originate within skin. And if you really want to see just how powerful EDA is, meet actor Michael Berryman. So my big question is, what was it like to be on Star Trek?

MICHAEL BERRYMAN OC
It was fantastic. I was the first Bolian.

NEIL SHUBIN VO
Blue skinned?

MICHAEL BERRYMAN VO/OC
Yes. I think we were a wonderful mutation.

NEIL SHUBIN VO/OC
Michael often plays monsters and aliens in science fiction movies. He suffers from a rare mutation in his EDA gene that stopped his skin organs from developing properly.

MICHAEL BERRYMAN VO/OC
I had the experiences at a very young age. I started realizing I had issues with my skin.

MUSIC OUT

MICHAEL BERRYMAN OC/VO
For instance, no fingernails. I have two nails here. One here, one here. One here and one here. The rest are not fully developed. There were areas that were just raw meat where there was no dermis on it at all. But I also realized that I, well I had no teeth. The teeth that I had had to be removed. I've worn dentures my entire life. It also affected me in the manner of which I cannot dissipate body heat, which is absolutely huge.

NEIL SHUBIN VO/OC
Yeah, I mean you're an actor. You're under hot lights. I mean, what do you do? What are the…

MICHAEL BERRYMAN VO/OC
Well, the acting came about secondary to my chosen profession, which was food and beverage. I was gonna be, I had a restaurant. I was on my way to be a chef. I started to realize that I would overheat quite readily. So the only way in which I could dissipate the body heat was actually physically. Meaning I would go into a freezer that was 20 below zero.

NEIL SHUBIN VO
Wow.

MICHAEL BERRYMAN OC/VO
And breathe slowly and deeply to cool the blood in my lungs.

NEIL SHUBIN OC
So sweat glands, finger tips and nails, hair?

MICHAEL BERRYMAN VO
Yes.

NEIL SHUBIN OC
As well.

MICHAEL BERRYMAN VO
Teeth.

NEIL SHUBIN OC
Teeth. I mean, these are all skin organs. So, you of all people understand just how important skin is.

MICHAEL BERRYMAN VO/OC
Yeah, I like it when it's healthy.

NEIL SHUBIN VO/OC
Michael's skin condition demonstrates the crucial role EDA has had in shaping our bodies. When we look at evolution, you know, we don't inherit structures from our ancestors. I mean I didn't inherit an elbow, you know, from the fish we found up in the Arctic. What we inherit are the developmental processes, the genes, the sort of the manufacturing processes, if you will, to build those organs. And EDA was a very important part of our evolutionary history.

MUSIC IN

NEIL SHUBIN VO
From teeth to hair and even skin glands the EDA gene helped shape the bodies of our reptile ancestors. And with every change they became more and more like mammals. But there was one more critical change that helped complete the transition to mammals. And it enriches our lives today. A new kind of ear. The hearing anatomy of mammals is unique. You won't find ear flaps on any reptile. Our ears are extremely sensitive, allowing us to pick up a wide range of sounds. From high pitched squeaks to low distance calls.

ROGER SMITH VO
Okay.

NEIL SHUBIN VO/OC
And the secret of their incredible sensitivity lies in the tiniest bones in our body. These are the three bones of our middle ear.

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NEIL SHUBIN VO/OC

All mammals, including people, have these three bones that sit inside the skull. And what they do is they form a little lever system that turns the vibration of air into sound that our nervous system can perceive. We, like all mammals, have three of these bones in our middle ear, but reptiles only have one.

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NEIL SHUBIN VO
These two extra bones, the malleus and incus, enable us to amplify sounds that reach our eardrum, which is one reason why our hearing is so much better than reptiles. This presents us with a simple, yet extraordinary puzzle. How did our acute sense of hearing, using three bones, emerge from our reptilian ancestors who used only one?

NEIL SHUBIN VO
For nearly two centuries scientists have been fascinated by this mystery. And one of them is my former student Karen Sears.

KAREN SEARS VO/OC
So these are the gray, short-tailed opossum. And they have been used in labs for a few decades and are now becoming a much more popular lab organism. They are very cute. So the opossums, like other marsupial mammals, the mother gives birth very early compared to what we would call placental mammals, things like us, like mice, like dogs. Now these guys, you know, they're a month and a half old. They're pretty big. When they're born they crawl up here and attach to these nipples. And they're only a few millimeters in length at that stage. They are almost at an embryonic stage of development. About the equivalent of a human embryo at about 40 days of development, so they don't really have hind limbs. They have no hair. They can't hear at all, at that point.

NEIL SHUBIN VO
These opossums are born just two weeks after mating. And Karen can see how their ear bones form at each stage of development from early embryo to adult. In order to find the bones, she euthanizes the opossums and uses flesh eating beetle larvae to strip away the tissue and leave bare bones. These dermestid beetles are used by labs and museums the world over. It takes about 24 hours for them to complete their work. Karen is then left with a series of skulls through which she can trace the development of the middle ear bones from embryo to adult. And what the skulls reveal is astonishing.

KAREN SEARS VO/OC
So what's really surprising is if you look at these early opossum embryos what you see is essentially a reptilian style ear with one ear bone. Those two extra middle ear bones, they're gonna be in the ear, in the adult. They are part of the jaw. And so the jaw joint between the skull and the jaw really looks like that of a reptile. Then after they're born and while they're growing up those little bones that are gonna be the mammalian middle ear, disconnect from the jaw. They get relatively smaller and move up to their final position to become a mammal-like ear. So, if you have modern reptiles with one bone, you have modern mammals with three ear bones. I think what the embryos do is they almost provide a link between those two. So what we see in the opossums is from that time they're born through they're adult they almost go through 300 million years of evolution in terms of their ears.

NEIL SHUBIN VO
How do we know that the bones we use to hear with came from the bones reptiles use to eat with?

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NEIL SHUBIN VO/OC
Well, this amazing transition we see in development from jaw bones to ear bones, we also see in the fossil record. And we see it in fossils from here in South Africa. And if we look at some of these primitive mammal-like reptiles we

see something in the lower jaw that's very different from us. Because what it has is one bone here, which carries the teeth and then there's a bunch of other bones that are sort of moderately sized that sit at the back of the jaw. They form the jaw joint itself. As you go forward in time what you start to see are creatures like this, which have a larger bone that holds all the teeth and ever smaller bones at the back of the jaw that form the jaw joint. Then we hit a point.

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NEIL SHUBIN VO
When you get to animals that lived around 200 million years ago, more recent in the fossil record, you find that they have formed a completely new jaw joint. That's because the bone that holds the teeth had grown so large it made contact with the skull. So, over millions of years bones that formed the old jaw joint began to shrink. And eventually became redundant. But instead of being lost altogether these old jaw bones were repurposed to take up a new role, in the ear.

NEIL SHUBIN VO
Finding out when that transition took place is difficult. Because the tiny ear bones sit loose in the skull and they are rarely found with the rest of the body. But recently a fascinating discovery was made in another part of the world. China. One of the leading scientists involved in the study is my colleague Zhe-Xi Luo who works in a lab next door to mine. So Luo is a fabulous anatomist. Here's a guy who knows the anatomy of the teeth, the anatomy of the jaws, the anatomy of the ears of reptiles and mammals as well as anybody on the planet. Furthermore, he's able to work with really tiny specimens.

ZHE-XI LUO OC/VO
When the fossil was first spotted in the field my friend thought it's just a pebble. He picked it up and he realized there were bones in that pebble. It's a fossil. After more detailed work we know that it's actually a mammal skull. And it's related to the origin of all mammals.

NEIL SHUBIN VO
The named it Hadrocodium. Using a 3-D printer Luo built an enlarged replica of its tiny skull. The teeth had cusps like other mammals. But it's the lower jaw that really stood out. The jaw joint looked remarkably like that of modern mammals, which suggests that the old reptilian jaw bones were no longer being used to eat with. They had become part of the ear.

ZHE-XI LUO VO/OC
On the inside of the jaw there are structures to hold the ear bone. This shows us Hadrocodium's ear bones are still attached to the jaw.

NEIL SHUBIN VO
But the attachment was minimal. Hadrocodium's ear bones were on their way to being completely separate. So this 195 million year old creature, no bigger than a paper clip, had taken a big step towards the kind of hearing we have today. Along with its specialized teeth and fur coat Hadrocodium is regarded as one of the earliest mammals. And there was a final surprise, another important mammalian feature inside its skull.

ZHE-XI LUO VO/OC
We originally thought the early mammals' brain were a lot smaller. But Hadrocodium really surprised us. It has a huge brain. In fact, its brain is 50 percent bigger relative to its body mass than anything before it. That's why we called the fossil Hadrocodium. It means it's got a great big brain.

NEIL SHUBIN VO

The question is, why would our ancestors have needed such a big brain in the first place? After all, they weren't building cities or writing Shakespeare. 195 million years ago a big brain helped them to survive in a dangerous nighttime world. The rise of a new kind of reptile, the dinosaurs, forced the early mammals to become tiny creatures of the night. From smelling to hearing to touching with their whiskers, processing so much sensory information caused their brains to grow. They hunted in the dark and hid in their burrows during the day. Many of them maintained that lifestyle for over 130 million years. Only when the dinosaurs were wiped out in yet another mass extinction 65 million years ago could the mammals truly emerge and flourish.

NEIL SHUBIN VO
So when the dinosaurs disappeared that's when mammals really took off in a big way.

ROGER SMITH VO/OC
That's right. They, they took the opportunity with all the vacant niches. The empty spaces on the land surface and they stepped out from the, under the dinosaurs' footprints and radiated and diversified.

NEIL SHUBIN VO/OC
So in a very real sense we wouldn't be here if it wasn't for the removal or death of the dinosaurs, right?

ROGER SMITH OC
Certainly.

NEIL SHUBIN VO/OC
Our earliest mammalian ancestors were tiny. But deep within their bodies, just as in ours, is an incredible history. The more you look at fossils, the more you look at embryos, the more you see that we're repurposed reptiles. The jaw I'm using to talk with, the teeth I use to eat with, the ear bones I use to hear with, the skin and the structures that appear within it, that arose are in our reptile past. So in a very real sense, every day we feel the consequences of our inner reptile.

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