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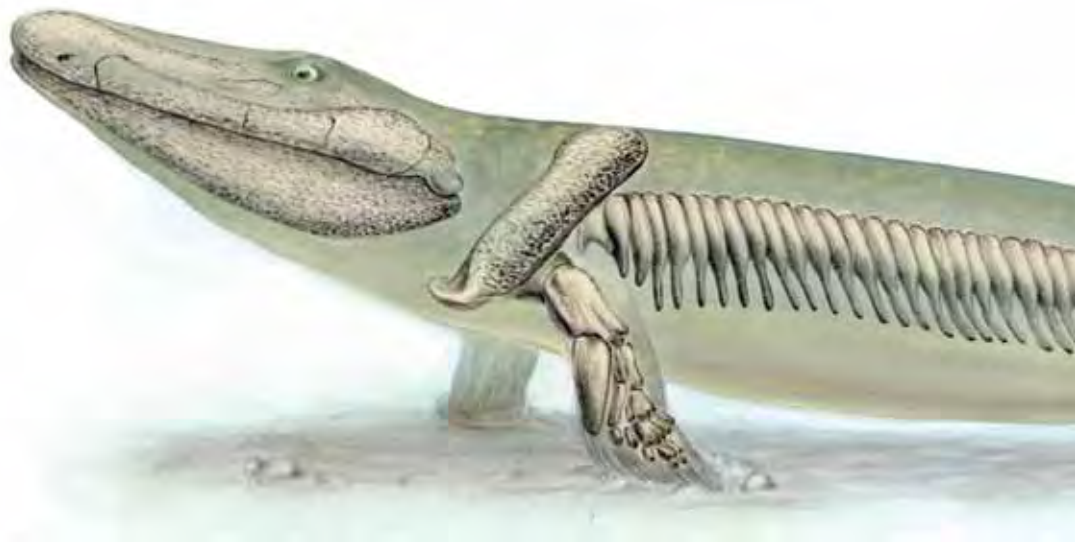
GENETIC ISOLATION

Studying the Hutterites

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FINDING FISH FINGERS AND WRISTS



by Neil Shubin, PhD

In 1995, Ted Daeschler and I had just returned to his house in Philadelphia after driving all through central Pennsylvania in an effort to find new roadcuts. We had found a lovely cut on Route 15 north of Williamsport, where PennDOT had created a giant cliff in sandstones about 365 million years old. The agency had dynamited the cliff and left piles of boulders alongside the highway. This was perfect fossil-hunting ground for us, and we stopped to crawl over the boulders, many of them roughly the size of a small microwave oven. Some had fish scales scattered throughout, so we decided to bring a few back home to Philadelphia. Upon our return to Ted's house, his four-year-old daughter, Daisy, came running out to see her dad and asked what we had found.

In showing Daisy one of the boulders, we suddenly realized that sticking out of it was a sliver of fin belonging to a large fish. We had completely missed it in the field. And, as we were to learn, this was no ordinary fish fin: it clearly had lots of bones inside. People in the lab spent about a month removing the fin from the boulder—and there, exposed for the first time, was a fish with [anatomist Sir Richard] Owen's pattern. Closest to the body was one bone. This one bone attached to two bones. Extending away from the fin were about eight rods. This looked for all the world like a fish with fingers.

Our fin had a full set of webbing, scales, and even a fish-like shoulder, but deep inside were bones that corresponded to much of the "standard" limb. Unfortunately, we had only an isolated fin. What we needed was to find a place where whole bodies of creatures could be

recovered intact. A single isolated fin could never help us answer the real questions: What did the creature use its fins for, and did the fish fins have bones and joints that worked like ours? The answer would come only from whole skeletons.

For that find, we had to search almost ten years. And I wasn't the first to recognize what we were looking at. The first were two professional fossil preparators, Fred Mullison and Bob Masek. Preparators use dental tools to scratch at the rocks we find in the field and thereby expose the fossils inside. It can take months, if not years, for a preparator to turn a big fossil-filled boulder like ours into a beautiful, research-quality specimen.

During the 2004 expedition, we had collected three chunks of rock, each about the size of a piece of carry-on luggage, from the Devonian

of Ellesmere Island. Each contained a flat-headed animal: the one I found in ice at the bottom of the quarry, Steve [Gatesy]’s specimen, and a third specimen we discovered in the final week of the expedition. In the field we had removed each head, leaving enough rock intact around it to explore in the lab for the rest of the body. Then the rocks were wrapped in plaster for the trip home. Opening these kinds of plaster coverings in the lab is much like encountering a time capsule. Bits and pieces of our life on the Arctic tundra are there, as are the field notes and



scribbles we make on the specimen. Even the smell of the tundra comes wafting out of these packages as we crack the plaster open.

Fred in Philadelphia and Bob in Chicago were scratching on different boulders at the same general time. From one of these Arctic blocks, Bob had pulled out a particular small bone in a big fin of the Fish (we hadn’t named it *Tiktaalik* yet). What made this cube-shaped blob of bone different from any other fin bone was a joint at the end that had spaces for four other bones. That is, the blob looked scarily like a wrist bone—but the fins in the block that Bob was preparing were too jumbled to tell for sure. The next piece of evidence came from Philadelphia a week later. Fred, a magician with his dental tools, uncovered a whole fin in his block. At the right place, just at the end of the forearm bones, the fin had *that* bone. And *that* bone attached to four more beyond. We were staring at the origin of a piece of our own bodies inside this 375-million-year-old fish. We had a fish with a wrist.

Over the next months, we were able to see much of the rest of the appendage. It was part fin, part limb. Our fish had fin webbing, but inside was a primitive version of Owen’s one bone—two bones—lotsa blobs—digits arrangement. Just as Darwin’s theory predicted: at the right time, at the right place, we had found intermediates between two apparently different kinds of animals.

Finding the fin was only the beginning of the discovery. The real fun for Ted, Farish [Jenkins], and me came from understanding what the fin did and how it worked, and in guessing why a wrist joint arose in the first place. Solutions to these puzzles are found in the structure of the bones and joints themselves.

When we took the fin of *Tiktaalik* apart, we found something truly remarkable: all the joint surfaces were extremely well preserved. *Tiktaalik* has a shoulder, elbow, and wrist composed of the same bones as an upper arm, forearm, and wrist in a human. When we study the structure of these joints to assess how one bone moves against another, we see that *Tiktaalik* was specialized for a rather extraordinary function: it was capable of doing push-ups.

When we do push-ups, our hands lie flush against the ground, our elbows are bent, and we use our chest muscles to move up and down. *Tiktaalik*’s body was capable of all of this. The elbow was capable of bending like ours, and the wrist was able to bend to make the fish’s “palm” lie flat against the ground. As for chest muscles, *Tiktaalik* likely had them in abundance. When we look at the shoulder and the underside of the arm bone at the point where they would have connected, we find massive crests and scars where the large pectoral muscles would have attached. *Tiktaalik* was able to “drop and give us twenty.”

Why would a fish ever want to do a push-up? It helps to consider the rest of the animal. With a flat head, eyes on top, and ribs, *Tiktaalik* was likely built to navigate the bottom and shallows of streams or ponds, and even to flop around on the mudflats along the banks. Fins capable of supporting the body would have been very helpful indeed for a fish that needed to maneuver in all these environments. This

interpretation also fits with the geology of the site where we found the fossils of *Tiktaalik*. The structure of the rock layers and the pattern of the grains in the rocks themselves have the characteristic signature of a deposit that was originally formed by a shallow stream surrounded by large seasonal mudflats.

But why live in these environments at all? What possessed fish to get out of the water or live in the margins? Think of this: virtually every fish swimming in these 375-million-year-old streams was a predator of some kind. Some were up to sixteen feet long, almost twice the size of the largest *Tiktaalik*. The most common fish species we find alongside *Tiktaalik* is seven feet long and has a head as wide as a basketball. The teeth are barbs the size of railroad spikes. Would you want to swim in these ancient streams?

It is no exaggeration to say that this was a fish-eat-fish world. The strategies to succeed in this setting were pretty obvious: get big, get armor, or get out of the water. It looks as if our distant ancestors avoided the fight.

But this conflict avoidance meant something much deeper to us. We can trace many of the structures of our own limbs to the fins of these fish. Bend your wrist back and forth. Open and close your hand. When you do this, you are using joints that first appeared in the fins of fish like *Tiktaalik*. Earlier, these joints did not exist. Later, we find them in limbs.

Proceed from *Tiktaalik* to amphibians all the way to mammals, and one thing becomes abundantly clear: the earliest creature to have the bones of our upper arm, our forearm, even our wrist and palm, also had scales and fin webbing. That creature was a fish.

What do we make of the one bone—two bones—lotsa blobs—digits plan that [Richard] Owen attributed to a Creator? Some fish, for example the lungfish, have the one bone at the base. Other fish, for example *Eusthenopteron*, have the one bone—two bones arrangement. Then there are creatures like *Tiktaalik*, with one bone—two bones—lotsa blobs. There isn’t just a single fish inside of our limbs; there is a whole aquarium. Owen’s blueprint was assembled in fish.

Tiktaalik might be able to do a push-up, but it could never throw a baseball, play the piano, or walk on two legs. It is a long way from *Tiktaalik* to humanity. The important, and often surprising, fact is that most of the major bones humans use to walk, throw, or grasp first appear in animals tens to hundreds of millions of years before. The first bits of our upper arm and leg are in 380-million-

year-old fish like *Eusthenopteron*. *Tiktaalik* reveals the early stages in the evolution of our wrist, palm, and finger area. The first true fingers and toes are seen in 365-million-year-old amphibians like *Acanthostega*. Finally, the full complement of wrist and ankle bones found in a human hand or foot is seen in reptiles more than 250 million years old. The basic skeleton of our hands and feet emerged over hundreds of millions of years, first in fish and later in amphibians and reptiles.

But what are the major changes that enable us to use our hands or walk on two legs? How do these shifts come about? Let's look at two simple examples from limbs for some answers.

We humans, like many other mammals, can rotate our thumb relative to our elbow. This simple function is very important for the use of our hands in everyday life. Imagine trying to eat, write, or throw a ball without being able to rotate your hand relative to your elbow. We can do this because one forearbone, the radius, rotates along a pivot point at the elbow joint. The structure of the joint at the elbow is wonderfully designed for this function. At the end of our upper-armbone, the humerus, lies a ball. The tip of the radius, which attaches here, forms a beautiful little socket that fits on the ball. This ball-and-socket joint allows the rotation of our hand, called pronation and supination. Where do we see the beginnings of this ability? In creatures like *Tiktaalik*. In *Tiktaalik*, the end of the humerus forms an elongated bump onto which a cup-shaped joint on the radius fits. When *Tiktaalik* bent its elbow, the end of its radius would rotate, or pronate, relative to the elbow. Refinements of this ability are seen in amphibians and reptiles, where the end of the humerus becomes a true ball, much like our own.

Looking now at the hind limb, we find a key feature that gives us the capacity to walk, one we share with other mammals. Unlike



Shubin holds a cast of his fossil discovery *Tiktaalik roseae*. Photo by Dan Dry

“The earliest creature to have the bones of our upper arm, our forearm, even our wrist and palm, also had scales and fin webbing.”

NEIL SHUBIN, AUTHOR

fish and amphibians, our knees and elbows face in opposite directions. This feature is critical: think of trying to walk with your kneecap facing backward. A very different situation exists in fish like *Eusthenopteron*, where the equivalents of the knee and elbow face largely in the same direction. We start development with little limbs oriented much like those in *Eusthenopteron*, with elbows and knees facing in the same direction. As we grow in the womb, our knees and elbows rotate to give us the state of affairs we see in humans today.

Our bipedal pattern of walking uses the movements of our hips, knees, ankles, and foot bones to propel us forward in an upright stance unlike the sprawled posture of creatures like *Tiktaalik*. One big difference is the position of our hips. Our legs do not project sideways like those of a crocodile, amphibian, or fish; rather, they project underneath

our bodies. This change in posture came about by changes to the hip joint, pelvis, and upper leg: our pelvis became bowl shaped, our hip socket became deep, our femur gained its distinctive neck, the feature that enables it to project under the body rather than to the side.

Do the facts of our ancient history mean that humans are not special or unique among living creatures? Of course not. In fact, knowing something about the deep origins of humanity only adds to the remarkable fact of our existence: all of our extraordinary capabilities arose from basic components that evolved in ancient fish and other creatures. From common parts came a very unique construction. We are not separate from the rest of the living world; we are part of it down to our bones and, as we will see shortly, even our genes.

ABOUT THE AUTHOR:

Neil Shubin is professor and associate dean for organismal and evolutionary biology at the University of Chicago and provost of the Field Museum of Natural History. In 2004, Shubin and his colleagues Ted Daeschler and Farish A. Jenkins Jr. lead the team that discovered *Tiktaalik roseae*. That discovery coupled with his experience teaching human anatomy to first year medical students at the University of Chicago prompted him to write this book. To learn more about the book, go to www.yourinnerfish.com.

