Your Inner Fish Study Guide

Your Inner Fish by Neil Shubin

BOOKRAGS

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Summary

“Your Inner Fish” by Neil Shubin is the author’s personal story about his many expeditions and years of study and research, of fossils that he dug up literally all over the world. From the Arctic Circle, to China, to Nova Scotia, Greenland and the American West Shubin was ready to pack his gear an go anywhere where he might be able to find more answers to the question that he was determined to have answered. Shubin, along with a wide swath of paleontologists, anatomists and biologists, were convinced that there was a missing link. Although this link involved man, it wasn’t the missing link that readily comes to mind. What Shubin was dedicated on finding was fossil evidence of creatures that left the sea for land. He knew it existed. Every finding by paleontologists and biologists from past times had found hints and clues that the creature existed. But where was the evidence? That was the question that Shubin was determined to answer.

Shubin has been convinced that the Arctic Circle held the best chance for discovery of this creature. He learned that the rocks were much older than many of the sites he’d been to. He had always found fossils and added to the growing evidence of the existence of the transformative species but he wanted the actual creature – the fossil evidence of this animal.

Shubin and his team headed to the Arctic Circle and found a plethora of fossils but not THE fossil. He was dismayed at not finding the fossil that he longed to find. He was literally packing up when a grad student who was part of the expedition found a mother lode of fossils. Shubin and his team tore into the area and sure enough—he found the link. Just as Shubin and many others predicted, the creature had elements of both fish and amphibian. They also learned from rock progression that the period that this creature lives was about 375 million years ago. Since Shubin and his colleagues discovered the creature, they were allowed to name it. They asked the Intuit tribe in the region for an appropriate name. The Intuits suggested “Tiktaalik,” which meant large fresh water fish. It was a sensation in the world of paleontology and even made the front page of some leading papers including the New York Times.

Despite achieving his goal with this important discovery, Shubin was far from done. He had more fossils to find and more intermediate animals to discover. In fact, his discovery led to more questions than answers and Shubin was determined to answer as many as he could. Shubin makes the connection between all species that ever lived and man. From the primitive microbe, to the jellyfish, shark, frog, polar bear and man’s best friend – man is related to all of them and Shubin has the proof.

Chapters 1 and 2

Summary

To Neil Shubin finding fish bones in the Arctic Circle is better than finding gold. Science learns about the human body from the skeletal remains of fish. There are many clues about man's structure of the human body. There are fossils only from a small fraction of all the extinct animals that ever lived and only a small fraction of those fossils are ever found. While Shubin and his colleagues were studying 375-million-year-old rocks on Ellesmere Island, they discovered the snout of a flat-head fish sticking out from a rock. Such a fish could reveal early stages of the human neck, skull and even limbs. Fish bones are used to learn about man's past.

Planning and predictability are both part of the process in finding fossils. Inspecting rock is the most important function for a paleontologist in the field. They seek out rocks of the right age, the type of rock that preserves fossils and rocks that are exposed at the surface. Of course, luck and fate also play a part in finding the right sight.

One of the great transitions in the history of the world is the invasion of land by fish. For billions of years, life only existed in water. Three-hundred and sixty-five millions ago life began to appear on land. The vast majority of rock layers and fossils are ordered by age progression. Rocks in different areas of the earth represent different eras of time. Predictions about fossils found in certain rocks can be based on living animals that evolved from them. Expeditions are planned based on these predictions.

Two fundamental categories of species include "everythings" (species with a head and two eyes) and "everythings with limbs." The first fish appears in the age progression chart before the first amphibian. DNA data is entered into powerful computers which provide groups and subsets within the groups. Scientists have established that mammals first appeared in the early Mesozoic and primates in the Cretaceous period. The fossil records found in rocks provides evidence of man's connection with the rest of the forms of life. The first fish to "walk" on land is a species that can be placed between everythings and everythings with legs and can most probably be found in rocks that are 375 million years old. Volcanic rocks and metamorphic rocks are not good fossil preservers. Sedimentary rocks including limestone, sandstones, siltstones and shale are ideal to preserve fossils.

Inside every rock is a history of what happened when that rock was first formed. To find the origin of limbed animals, research must focus on rocks that are 375 million years old, that were formed in water and that are visible. Paleontologists often spot the emergence of bones from a rock and start digging. Deserts and Arctic regions are prime locations for fossil hunting. Cost is a consideration, especially for graduate students.

In his first dissection of a human, Shubin felt a distance until they cut open the hand and he felt an emotional connection. He wondered what it was about the hand that got him.

He attributed it to the complexity and utility of the hand. Sir Charles Bell called the hand “perfect.” Anatomist Sir Richard Owen concluded in the mid-1800s, that there were “exceptional similarities” between species as different as frogs and humans. Shapes and sizes are the main differences. Shubin concluded that the history of limb pattern would be found in the fin skeletons of fish.

At first glance, there is no similarity between human limbs and fish fins. German anatomists made a startling discovery in the mid-1800s. They found a fish that had a set of lungs at the back of its throat. Other such fish, called lungfish, were found in Africa and Australia. The fins were unusual in lungfish in that they hand a single bone, the humerus, like the bone that attaches to the human shoulder. A fossil with a mix of fish and amphibians was found in Quebec. The history of this species was found in Devonian age rocks that are 360 to 390 million years old. The history of fingers and toe was hidden in those rocks.

In the 1920s Swedish paleontologist Gunnar Save-Soderbergh, found what some called the missing link in Devonian rocks on the east coast of Greenland. It was called ichthyostega but it did not contain the secrets of the origin of limbs. Shubin’s colleague, Jenny Clack, discovered another fossil at the sight that was truly remarkable. A second discovery by Save-Soderbergh was the Acanthostega gunnari which had limbs with fingers and toes but the limbs were shaped like flippers which meant that early land travelers had these appendages to help them swim, not walk. The origin of this species was a mystery until 1995.

Shubin and Ted found the fossil of a large fish in some boulders in Pennsylvania. Once the fossil was removed and examined it was found to have the expected webbing and scales of a fish but inside the fin were the bones that correspond with human limbs. They needed to find a fossil of the entire fish to learn more. Working with rock Shubin brought back from the Arctic, fossil preparator Bob Masek pulled a bone from the fossil of a species that was later named the Tiktaalik and discovered that it had a joint and spaces for four other bones. It looked like a wrist bone. Soon after preparator Fred Mullison uncovered an entire fin that had the wrist-like bone. They had a fish with a wrist. They were able to see that the appendage was part fin, part limb and how the bones functioned together.

The Tiktaalik was designed to walk on the bottom of shallow ponds and streams. The eyes on top of his head enabled him to see over the surface of the water. What compelled them to get out of the water altogether – huge predators that preyed upon them. In that era there were huge fish that were twenty-feet long. Modern man uses the same limb, wrist and finger bones as those that existed in early creatures that lived hundreds of billions of years ago. Over the eons, bones were refined to be more versatile. The early “fingers” could not grasp a baseball. Like fish, human embryos begin with knees and elbows pointing in the same direction. But as the embryo develops, the knees and elbows rotate. Human hips are positioned differently than those of the crocodile. Human hips keep the legs under the body; the legs of crocodiles are sprawled out to the side.

Analysis

The author provides a look inside what a field paleontologist does. He describes how experienced scientists like Shubin know from available data where to find the fossil they seek, what kind of rock it will be in and whether the top rock will be visible and therefore accessible for digging.

The author speaks with passion about his field of work and lays the premise for the book – that man is not only connected to fish that he, in fact, has a link with every creature that ever lived including microbes. Shubin has a great respect and admiration for rocks. They are in most cases the only witness to what the earth was like billions of years ago. From a rock, scientists can determine what the climate was like and whether the area had originally been in the ocean or on a mountain.

Shubin describes his joy in discovering the Tiktaalik which was one of the intermediate animals that linked fish with amphibians.

Vocabulary

bizarre, decipher, paradoxical, paleontology, serendipity, igneous, metamorphic, sedimentary, esoteric, concoct, prohibitively, conical, quintessentially

Chapters 3 and 4

Summary

While Shubin and his colleagues were digging up the Tiktaalik in the Arctic, Randy Dahn, a researcher in his lab was in Chicago conducting genetic experiments with the embryos of sharks and skates. He injected strong doses of Vitamin A in the eggs containing skate embryos. The goal was to find the DNA code that builds bodies from eggs. This quest would take them from the human hand to shark fins and to the wings of flies. Shubin's lab is split between work on fossils and embryo DNA.

DNA provides instructions to build diverse cells – limbs, nerves, organs – but they all contain the same DNA. What creates different results are the genes that are turned on in each cell. Genetic switches control the genes in each cell. At conception, a single cell contains all the DNA code necessary to build the body. As the body is built, genes are switched on and off at just the right moment. Using this methodology, the genetic switches that may have changed a fin to a hand can be identified.

Sharks are the earliest creatures to have a fin with a skeleton frame. The bones in a shark's fin are shaped like rods and are long and short and thin and wide and are made of cartilage. Shark embryos were difficult to find. So they gathered skate embryos which were much more readily available. Since Tabin's discovery of the hedgehog gene, it had been found in many species. Randy discovered the Sonic hedgehog gene in a shark.

If the limb of a chicken or mammal with vitamin A, a patch of tissue that has Sonic hedgehog activity on the opposite side develops. The embryos of skates were injected with vitamin A with an end result of a mirror-image fin. The injected some mouse Sonic hedgehog into the developing skate resulting in different shaped rods in the fin. The inner fish was in the biological elements that build the fins. This meant that the transition of fish to land was likely due to genes involved in shark fin development used to make different appendages. The link between species is undeniable.

A lot of information about a species is found in their teeth. Teeth are the hardest part of an animal's body which is why they are sometimes the only bones left on an animal. Reptiles like crocodiles have the same teeth throughout their mouths except some are larger than others and missing teeth are continually replaced. In older rocks, reptilians are found that walk on four legs like dogs but there are no other similarities. Up higher in the rocks, are the first remnants of the first mammals that have smaller teeth and jaws that move toward the ear. The rocks of 200 million years ago show the first rodents that look like mammals.

Shubin chose to do his graduate work at Harvard because of Dr. Jenkins's expeditions to the Western America to learn how mammals developed their chewing abilities. Working with seasoned paleontologists like Chuck Schaff and Bill Amaral he learned how to recognize bones, teeth and skulls. Shubin acquired the ability to spot teeth

among other rocks. By the time Shubin joined the expedition, Farish and his colleagues had already found a fossil-rich layer of rock. Early mammals were so tiny that it was easy to miss their teeth.

Shubin got the expedition bug after that experience and selected the coast of Nova Scotia where 200 million year-old Triassic and Jurassic rocks lay on the surface. He recruit an expert on these rocks, Paul Olsen, to go with him. Dr. Jenkins funded the expedition and suggested that Shubin bring Chuck and Bill. They spent two weeks digging and found fragments of bones. Shubin was disappointed that they hadn't found more. However, when they returned to the lab with the help of a microscope they realized they had uncovered a small jaw with a few teeth.

What was stunning about the discovery was that the jaw represented a creature that was part mammal and part reptile – the tritheledont. This species presented an occlusion that was like that of a mammal while it had other characteristics of a reptile. The tritheledont also displayed other mammalian features like a lower jaw, skull and skeleton. Shubin and the others returned the next summer and found a fossil rich layer of rock that had thousands of tiny bones. They brought tons of rocks back in which they found the fossils of many species.

About 150 million years ago, rodents appeared with a tooth row that is similar to that of humans. The teeth were made up of incisors, canines and molars the same mix as found in humans. Thanks to this rodent and its different kinds of teeth, humans are able to have the wide-ranging diet that they enjoy. Teeth are hard because of a crystal molecule contained inside of them and the enamel on the outer part of the teeth. Teeth have to be harder than what they have to chew.

Fish, amphibians, reptiles, birds and mammals all have hydroxyapatite-containing structures that make for hard bones and teeth. Conodonts are some of the most common fossils found in ancient oceans. Scientists at first disagreed about what they were – animal, vegetable or mineral. Later it was solved when they showed up in fossil rocks. They were the teeth of jawless fish called lampreys. Everything but the teeth vanished over the ages because the bodies were soft and the teeth were hard. One of the first bony-headed animals was the ostracoderms which are about 500 million years old. There is a plate-like region on their head that has the same construction of a human tooth – enamel, dentin and pulp.

The development of teeth follows the same pattern as the development of all structures that develop within skin including scales, hairs and feathers. Two layers of tissue come together, fold and secrete proteins. The genetic switches that go off to create the patters are essentially the same. Teeth establish the pattern for the other structures of the skin in the body.

The first four chapters focused on how the same organ can be traced to different species and how different versions of human organs can be round in rocks. Similar bones can be found in species as seemingly diverse as fish and humans. The same genetic switching patterns and DNA coding are also found in different creatures. There

is a similar theme to the construction of teeth, feathers and hair. Diverse creatures are actually just the variation of the same theme.

Analysis

This section contains the very precise descriptions of the process that the body building genes undertake to make hands. The author stresses how the hand is one important characteristic of humans and some mammals that fish, amphibians, and reptiles do not have. However, fossil research has proven that all the elements of the hand and fingers were present in creatures that had no limbs but were just waiting to evolve. Found inside the fin of some fossil fish were the same bones that are in the human arm. Shubin and his team found the fossil of a fish that had a bone in its fin that had a wrist. Shubin also provides the advances that have been made by paleontologists who focus their study on the fossil teeth of creatures. The hardest element on any species is its teeth which is why that is sometimes the only part of a creature that survives the ages.

Vocabulary

microscopic, demarcate, cartilage, pantheon, shrift, macerate, carnivore, anatomist, occlusion, juxtaposition, axiomatic, promontory, onerous, enigmas

Chapters 5 and 6

Summary

The brain is an organ that reveals a pattern of order that at first blush seems chaotic. Skulls are comprised of three elements: think plates, blocks and rods. The plates cover the skull while the blocks are underneath the brain and hold it in place. Other bones are found in the jaws, ears and throats. The brain is the largest organ in the skull. Small organs are the eyes, ears and nose. The head has muscles for biting, talking and moving our eyes and head. Nerves take information from the nose, ears and eyes to the brain.

The trigeminal nerve and the facial nerve both originate in the brain and have networks of nerves that branch off. The trigeminal branches control muscles and carry sensory data to the brain. The facial nerves control muscles and also carry sensory information. The facial nerves allow us to smile, frown, raise and lower eyebrows.

Studying these nerves, Shubin wondered why both the trigeminal and facial nerves sends branches to the ears and other areas of the head. The history of these nerves starts in the fertilized egg. As an embryo develops, the head first looks like a glob. Four blobs separated by creases develop in what will be the throat. The cells inside each blob are called arches will develop into either bone, muscle or blood vessels. The reason the trigeminal nerve sends branches to the ear is that all the structures it supplies had developed in the first arch. The reason that the facial nerve sends branches into the ear is that the muscles in the ears are derivatives of the second arch. In other words, the ear is developed from cells in both arches so the trigeminal and facial nerves both have roles in its development.

The human body is segmented which can be seen in the vertebrae. Each vertebra represents a segment of the body. Heads also contain a segmented pattern. Missing arches (cells) in the brain are the cause of birth defects. The arches in the human brain are also a direct link to sharks. The four blobs that are separated by creases in the human embryo look like the throats of fish and sharks. The head of every species from human to shark has four arches in development and a comparison of the elements of each demonstrates their similarities.

During the first three weeks after conception, genes in the arches are turned on and off. This activity sends instructions to cells to create different parts of the brain. Taking a frog embryo and intervening with the gene instructions produces mutants like a frog with two jaws for example. Although worms have no head or bones, man has a connection to them. Amphioxus is a worm, an invertebrate, that shares a number of characteristics with fish, amphibians and even mammals. The nerve cord that runs along its back is comparable to the spine and vertebrae. Worm fossils found in China and Canada that are over 500 million years old also have nerve cords. The Amphioxus also has gill

arches that were not used in the same way as in human development but they are there and contain the basic structure of the human head.

The human body is an elegant assembly of two trillion cells. The basic structure and organization of the human body sets it apart from those of primitive creatures. The jellyfish architecture is organized into disks and has a top and bottom like humans but unlike humans has no front and back or head or tail.

Shubin entered graduate school to study fossil mammals but got sidetracked. He soon became excited about the embryonic development of fish, amphibians and chickens. It was startling to see how much the development of the embryos of fish, chickens and amphibians was so much alike. In the 1800s, Karl Ernst von Baer, a natural philosopher, studied embryos in an effort to find a grand plan for life on earth. One of his conclusions was that all organs in the chicken were traceable to one of three tissue layers in developing embryos. He then compared his findings to a variety of species – fish, reptiles and mammals – and found these same three tissue layers in every one.

After the human egg is fertilized it goes through some changes and gets to the blastocyst stage which is fundamentally a ball of cells. This blastocyst then attaches to the mother's uteral wall to share the bloodstream. A blastocyst that attaches in the wrong place is referred to as an ectopic implantation and will result in a failed impregnation. The entire human body is formed from the top part of the blastocyst, the part that is implanted in the uteral wall. Cells divide and move and tissues move and fold to create a tube-like structure that has two layers. The three layers that von Baer found in the chicken over 200 years ago are all there in the human embryo. The outer tube is called the ectoderm – the skin and nervous system; the inner layer is the endoderm – the inner structures of the body; and, the middle layer is the mesoderm – the skeleton and muscles.

Von Baer's approach varies from the "ontogency recapitulates phylogeny" advocated by Ernst Haeckel. He believed that the human embryo went through fish, reptile and mammal stages. He stressed the differences between the human embryo and an adult fish or amphibian. A better comparison is between the embryos of a human and a fish. Von Baer's theory has been widely accepted over that of Haeckel. But comparisons evoked the basic question: what mechanism makes tissues and cells form bodies?

In 1903 German embryologist Hans Spemann who was determined to discover where the body-building information resided. He experimented with newt eggs and concluded that one egg can become more than one individual. Early embryonic eggs can form a whole new individual on their own.

Could man be related to invertebrates like coral or jellyfish? Sea anemones are shaped like tree trunks with a bunch of tentacles at the top. Researchers have found that these creatures have some of the same body organization genes that humans have. The genetic recipe that builds our body has been around since life began – it's just been altered as its been passed down.

Analysis

In this section Shubin describes the evolution from microbe and one-celled creatures that had been the only form of life for billions of years. The animals that evolved from the microbes were animals with heads while the microbes were essentially blobs with no head or tail. He parallels the development of the head with the development of the body. Fossil evidence indicates that the head is organized and ordered just as the body is. Body building is done in both the body and the head by DNA instructions to the cells that switch on and off to make the various parts of the body or head. The cells create molecules that serve as messengers between cells. Dysfunctional cells that are interrupted from this process will result in mutations.

Vocabulary

nanosecond, olfactory, innervate, redundant, apocryphal, epiphany, voracious, mandible, dichotomy, pliant, decipher, anecdote

Chapters 7 and 8

Summary

Human bodies look different than jellyfish because what makes us different is what's locked in our cells. A mass of bacteria or a group of skin cells is not a clump of cells. The component parts of cells work together to make the whole. Just as our bodies divide functions between different parts or organs, this division of labor extends to the microscopic parts like cells, genes and proteins. Skin cells continuously die and flake off but the individual remains the same. When a group of cells become a tumor when they stop cooperating with the other cells. They destroy the balance that's necessary to maintain life. The communication between cells and their ability to make molecules comprises the "tool kit" that's necessary to build all of Earth's forms of life.

The vast majority of the life that has occurred on life has been single-celled creatures. The more complex species, like man, has only been around for a fraction of Earth's existence. In the 1920s and 1930s, Martin Gurich, a German paleontologist, discovered flat, disk-like fossils in what is now Namibia. Similar fossils were found in Australia. No one was excited about them because it was thought they came from relatively new rocks.

In the mid-1960s, Austrian Martin Glaessner who lived in Australia discovered that these types of rocks were actually 15 to 20 million years older than originally believed in an era called the Precambrian which translates as "before life." The fossil disks proved to be the first form of life with bodies and that multi-celled creatures began to populate the seas 600 million years ago. There was structure and symmetry to these beings. These Precambrian creatures tell science when life as we know it started.

The structure of the human body originated in single-celled animals. The glue that holds cells together allows cells to communicate and forms the bodily structure. This "glue" is a variety of molecules and connect cells and fill up the space between them. Molecules are the connective element that makes the construction of the body possible and that keeps it together. The molecular structure of skeletons demonstrate how tiny molecules can create hard and strong structures.

Cells are highly organized on bones, particular on the outer side of them. Some cells adhere together and some are separated. Between the separated cells are the molecules that define the strength of the bone. These molecules combine to create collagen which is the most common protein found in the body. Bones sit in a mixture of hydroxypatite, collagen and other proteins. Cartilage is the tissue that allows the bones to glide against each other. Proteoglycan complex is a molecule that strengthens cartilage.

Whether an animal has bones or not, the common material that all species have between their cells are a mix of molecules that include collagens and proteoglycans.

Collagen makes up 90 percent of the body's protein weight. The molecular structure enable cells to organize and that bone cells stick to bone cells and skin cells to skin cells, etc. The most important function of the cells is their ability to communicate with one another. In order to accomplish this communication molecules move from one cell to another with a message. It is molecules that can cause the switching on and off of cells.

The placozoans are blob-like creatures that have four types of cells. Even with the limited number of cells, there is a division of labor among them. The cells contain the molecules that cause cells to adhere together and those that enable cell communication. In the early 1900s, H.V.P. Wilson broke sponges down into clumps of cells and put them in a dish. He watched as they fumbled around for a time and then was astonished when the pieces of the sponges came together and formed an entire new sponge body. Sponge cells have division of labor and the ability to communicate just as in other species.

In the early 1980s, tensions existed between molecular biologists and ecologist, anatomists and paleontologists. The former was seen as more advanced and sophisticated. Molecular biology was making great strides in anatomical and developmental biology. Shubin continued to dig and collecting DNA to learn more about its role in development. Fossils and geology remain powerful tools to learn about our past and ourselves.

Genes that contained the sense of smell are in every cell but are only active in the nasal area. The molecules that carry the odor are light and suspended in air. The molecules then travel to the nasal area behind the nose where there is a lining of mucous with nerve endings that trap the molecules and send a signal to the brain. Just like most animals, man's ability to smell is housed in the head.

In 1991, Linda Buck and Richard Axel discovered a large group of cells that provides us with our sense of smell. They approached their research making three assumptions: the shape of the genes that make odor receptors; that these genes were only active in tissues that participate in smelling; and, that there had to be a great number of this kind of gene. They were right on all three assumptions. They also discovered that three percent of all genes are dedicated to odor detection. Buck and Axel were awarded the Nobel Prize in 2004 for this work.

The olfactory genes discovered by Buck and Axel proved to be important in the history of life. Advanced fish and mammals have genes for both air and water receptors. Jawless fish like the lampreys have combined air and water receptors which confirms how primitive they are. The more advanced a species is the more odor detection genes he has. A large number of odor detection genes in humans have mutated and are useless. Research found that primates that develop color vision have an increased number of mutated olfactory genes. The body changed smell genes for the more sophisticated color vision which can make the distinctions necessary for survival. In the past, animals depending on catching scents for survival. As time passed and animals

evolved, enhancements in sight made it unnecessary for the body to depend on the thousand or so smell genes. Those genes are still there; they're just not active.

Analysis

The author continues in his descriptions of the bodybuilding process with emphasis on what is involved in the building of bones and the role that cells and molecules have in their construction. He also focuses on the process that the body undertakes in building scent receptors. A large number of cells are devoted to scent receptors which, Shubin explains, is possibly a throwback to mammals and other creatures that depended on their scene for their food and to avoid their enemies. The author goes into great detail explaining the intricate construction of the nasal system and how the nerves that originate from the brain send signals back to the brain when an odor is received. The brain is then able to react to the odor by taking the appropriate action.

Vocabulary

paleontologist, amorphous, collagen, enigmatic, flagella, disaggregated, microbial, genome, virulent, ad infinitum, predation, counterintuitive, paradox

Chapters 9 and 10

Summary

While in China on a dig to find salamander fossils in northeast China, Shubin stumbled onto one of the finest salamander fossils ever discovered. A fossil dealer in a mineral shop bargained in Chinese with Shubin's companion, Gao Keqin, who finally convinced the dealer to let them see a special fossil he had in the back room. The larval salamander fossil was about three inches long and contained great impressions of the entire animal. The most amazing feature was the eye of the creature. Shubin was staring at the eye of an ancient salamander. The majority of the images that we "see" actually happen inside our brains. The eye is designed to capture light and transmit it to the brain. The eye acts as a camera. Every animal that has a skull from fish to mammal has the same type of eye.

Genes build the eye, tissues are used to see and molecules gather light. When a molecule gathers light it changes shape and splits into. The part that breaks of is a protein known as an opsin. This split activates a series of reactions which results in a neuron sending a message to the brain. There are three or four light-gathering molecules to see color. Black and white vision requires only one molecule. Every species sees using the same process.

These molecules behave in a similar manner to molecules found in bacteria. Modified remnants of bacteria can be found in modern human retinas. Examining the opsin protein in different species can provide some of the history of our eyes. One important development was the ability for primates to see in color. Most mammals have two light receptors; however, primates have three. Therefore, many animals do not see in the depth of color as humans do. Why did color vision evolve? There were changes in the forests and flora at the time of the change which was about 55 million years ago. Monkeys in trees had to distinguish between fruits and leaves and flora.

Sound waves enter the ear and make the eardrum rattle which causes a gel to swish around and send a message to the brain which it interprets as sound. There are three parts of the ear: external, middle and inner. The external ear is the visible ear; the middle ear is comprised of small bones; and, the inner ear is comprised of nerves, the gel and tissue. The visible ear is a relatively new product of evolution. There are no fish with visible ears. The inner ear of humans has a connection to sharks which don't have ears.

Most instinctive traits of mammals lie within the ear. The three ear bones in mammals are the malleus, incus and stapes. In 1837, German anatomist Karl Recihert was studying the embryos of mammals and found that two of the ear bones in mammals corresponded to parts of reptile jaws. He concluded that the same gill arch that formed the mammal ear bones also formed the reptile jaw. In 1910, German anatomist Ernst Gaupp issued an extensive study of embryonic mammal ears. His work confirmed that

the three mammal bones in the ear make the connection between reptiles and mammals. Gaupp did all his work on living animals as opposed to fossils.

In the 1840s new kinds of dog-like fossils were being discovered in South Africa and Russian. These animals had traits of both reptiles and mammals. Part of their skeletal structure was reptilian while their teeth were mammalian. They came to symbolize the transition between reptile and mammal. The majority of this species had only one ear bone like a reptile. But the jaws got smaller and smaller as the animals advanced toward the transition to mammal until they ultimately wound up in the middle ear.

A tiny bone deep inside the human ear is the same as a large rod in the upper jaw of the shark. The origin of this bone is from the same arch. The shift of this bone occurred when animals began to transition to land. The inner ear is located deep inside the skull. The inner ear consists of rubes and gel-filled sacs. The inner ear has more than one function. One part of it is used to hear and another one has a role in balance. The inner ear tells us which way we are tilting and how fast our head is moving. Each time the body starts or stops the gel in the inner ear shifts which causes the nerve cells to bend and generate a current.

The eye muscles are connected to the system that the body uses to detect position and acceleration. There are eight small muscles on the side walls of the eyeballs that give the eye with the ability to move. There are voluntary and involuntary eye movements. Sensors in the head send a message to the brain on the direction and speed of these movements. Drinking too much alcohol will confuse the ear-eye connection. As the ethanol from the alcohol enters the inner ear from the bloodstream it is like mixing oil and alcohol. The gel floats around on the ethanol and it tricks the mind into thinking the body is moving. The eye twitch that is seen in a drunken person is caused from the malfunction of the system due to the overindulgence of ethanol. Hangovers are due to remnants of ethanol that remain in the inner ear even though the liver has cleared out most of the ethanol and the person is no longer “drunk.”

Fish like trout use a mechanism that tells them the motion of the water. It tells them where their safety zone is. Fish had sensory receptors that run down the length of their bodies. The system works much like that of the human ear. Water flows around these receptors, called neuromasts, and triggers the mechanism that sends a message to the brain. Sharks and fish can then determine the flow of water and if there is a disturbance in the water.

The eyes and ears share a common and ancient history. The box jellyfish is equipped with a devastating poison. They are different than other jellyfish species in that they have eyes – twenty of them. Some of the eyes are similar to the human eye. The human eye is controlled by a gene that is similar to a gene in primitive creatures like the jellyfish. The connection between the eye and ear is undeniable. Often when there is a birth defect involved the eye the ear is also involved and vice versa.

Analysis

The emphasis in this section is on the construction of the eyes and ears and how these two sensory systems have a deeply rooted connection to one another. He also compares the eyes and ears of man with that of other creatures, past and present, and makes the case for the many similarities that are present in them. He describes how a mutated cell is responsible for “eyelessness,” a rare disease that is found in all species including humans. The medical world can confirm the connection between the eye and ear. Oftentimes birth defects involving one of these organs will involve the other. Shubin stresses that the connection between the eye and ear is the nerves and branches of nerves that originates in the brain.

Vocabulary

illicit, mosaic, monochromatic, aniridia, geneticists, mélange, intemperate, savannahs,

Chapter Eleven and Epilogue

Summary

Shubin began his professional association with academia when as a college student in the early 1980s, he volunteered at the American Museum of Natural History in New York City. He enjoyed the weekly seminars that sometimes devolved in shouting matches. Shubin shrugged off taxonomy – the cataloguing of species – as mundane and unexciting. He later understood that their debate was over the most important concepts in all of biology. It has led to the development of methods that can be used to trace our lineages, nab criminals with DNA evidence, understand the AIDS virus, and track the spread of disease.

Every living creature had a predecessor parent and is a modified descendant of that parent. An individual may resemble his father or mother but he is a modified version of them and they are a modified version of their parents. Science provides a biological mechanism that will accurately trace our lineage. Descent with modification can be detected. If our lineage extends back to pond scum, specific predictions can be made. Every creature on earth should have the mark of descent of medication.

There is an organization to the construction of the bodies of all creatures. There is symmetry between man and many other creatures – two hands, four limbs, and one head. Humans share hair, mammary glands and four limbs with polar bears. There are fewer similarities with turtles but there are some – four limbs, two eyes. Humans share fewer similarities with fish – two eyes, four appendages. Human's share the most similarities with mammals because, for one reason, mammals are newer inhabits of Planet Earth than reptiles or fish.

While humans have characteristics that can be traced to the Tiktaalik, the link between fish and amphibian, they are not ancestors – they're more like cousins or distant relatives. However, every human is related to different degrees to every human who ever lived which can be proved by DNA. The fish, turtle, polar bear, human connection is confirmed by anatomical, physiological and cellular features and characteristics. The fish to human link is strongly supported by scientific evidence as well.

The human body is linked to many other creatures including jellyfish, worms and fish. There are remnants of each of these creatures in human cells; however, humans are modified descendants and possess unique traits and characteristics. The creatures that man is related to are multi-cellular and have body plans although the body plans are modified from creature to creature. The oldest multi-celled fossil is 600 million years old; the oldest creature with a three-boned middle ear is less than 200 million years old; the oldest bi-pedal creature is 4 million years old. Humans have inherited characteristics from creatures at every age of life. This history has impacted our lives and will continue to do so.

Doctors refer to injuries to the medial meniscus, the medial collateral ligament and the anterior curiae ligament as the “Unhappy Triad.” These are parts of the knee that are commonly injured. Perhaps having an inner fish has made these parts particularly vulnerable since fish weren’t bipeds. Humans are soaped-up version of fish. It walks, it talks, it wiggles its fingers. Modifications have their downside and our distant pass comes back to haunt us.

Man’s distant history was in streams and savannahs not in offices or ski slopes. The human body was not designed to play football. Every malady that humans suffer from can be traced to a historical component. All species that man is connected with have led active existences. Today’s man spends less time being active than any other creature. The experiences of the species from which we descended did not prepare humans for a sedentary life. The diseases that are the biggest killers of man can be associated with this lifestyle. Early ancestors had boom-bust diets – periods of bountiful amounts of food to famine. Fat was stored for those lean times. Today’s man generally never experiences famine yet we store fat that is never burned off. This fat storage leads to heart disease, stroke, diabetes and many other diseases.

Man’s transition to “talking” has come at a price. It was something that man’s ancestors did not do. Reconfiguring muscles and cells to talk has caused choking and sleep apnea problems. Hernias, which have become a common condition in today’s world, are the result of taking a fish body and reshaping it into a mammal.

Mitochondria are present in every cell of our bodies. Their function is to convert oxygen and sugar into energy that can be used outside the cell. They also metabolize toxins in regulation other cell functions. Malfunctioning mitochondria are responsible for a litany of disease that affects everything from the eye to bodily systems.

The process of turning oxygen and sugar into energy can be traced back billions of years ago and still exist in microbes. Their bacterial past can be utilized to study the diseases they cause. A team of scientists studied a disease that kills infants born with it. This condition interrupts the metabolic function of the mitochondria. The team detected a change in the DNA. The scientists were able to duplicate this change in a microbe and answer many questions about the condition and its prevention.

The research done by scientists from paleontologists to anatomists to molecular biologists provides insight into the root causes of many diseases and disorders. The advancement in the knowledge of man’s ancestors and their pasts paves the way for the creation of tools and methodology that will make man healthier and allow him to live a longer and more satisfying life.

As the father of young children, Shubin finds himself at the zoo more often. A special incident occurred with his son at the Museum of Science and Industry in Chicago. They saw the Apollo 8 capsule that was battered and beat up from its re-entry into Earth’s atmosphere. Shubin was excited. As a young boy he followed the Apollo 8 space flight. His son wasn’t interested in the least. Shubin told his son the story of Apollo 8. Shubin had an emotional experience about seeing the old space capsule. It reminded him that

man should not be afraid or suspicious of the unknown. It should spur man on to seek answers.

Analysis

In this last portion, Shubin reiterates much of what he had already covered and stresses the importance of the work of paleontologists and other scientists who study what went before man.

He also sounds a note of caution about the future health of our species. As he points out, man was not designed to be sedentary, a lifestyle choice that leads to many diseases including heart trouble, diabetes and stroke. Shubin inserts himself in a current debate that is taking place in the nation. He states that man was not designed to play football. He, of course, is referring to the head injuries that are sustained playing football. Shubin underscores that there is a price to pay when modifying our body in ways that it was not naturally designed to function.

Vocabulary

taxonomy, hypothesized, arbitrary, commonalities, predilection, jettisoned, propensity,

Important People

Neil Shubin

Neil Shubin is a field paleontologist and professor of anatomy at the University of Chicago and provost of the Field Museum in Chicago. He has had a lifelong career as a scientist and his passion is fossil hunting and trying to piece together the mysteries of creation and the evidence of the connection between man and all other species. Shubin has been literally all over the world in his quest to find fossils that will help to advance knowledge and benefit mankind.

Shubin has led expeditions to the Arctic Circle, Greenland, the American West, Canada and China among many other locations. He and his colleagues have made some astounding discoveries that have rocked the world of paleontology. In an expedition in the Arctic Circle that Shubin had targeted as one of the most likely spots on Earth to find a very elusive creature that he'd been searching for.

Shubin like his colleagues and team knew that there were transitional creatures that came between fish and amphibians. These creatures were believed to have been fish that had basically sprouted some features of the amphibian. They based these beliefs on known facts and because logically speaking there had to be an intermediate creature that could swim like a fish but also fumble its way on land. Shubin's quest was to find the fossil of that creature.

After weeks in the Arctic Circle just when Shubin was ready to call it a day, disappointed that they hadn't found the fossil, a colleague stumbled onto a large cache of fossils. The team found the rock layer that corresponded to the fossils first uncovered and found the creature that had characteristics of both a fish and an amphibian. The Intuits suggested the name, Tiktaalik. This discovery sent shock waves out in the world of paleontology. It made headlines around the world including the New York Times.

Although the discovery of the Tiktaalik was the highlight of Shubin's professional career, his passion to find more undiscovered fossils has not diminished. He wrote "Your Inner Fish" in hopes of enlightening the general public about man's connection with all creatures, past and present.

Hilde Mangold

In the 1920s, Hilde Mangold was a graduate student in the laboratory of German embryologist Hans Spemann. She was apparently very nimble-fingered and was able to conduct some very detailed experiments. Mangold focused her work on the embryos of salamanders at a stage of development when their diameters were around one-sixteenth of inch. Mangold wanted to see what happened if she transplanted part of a salamander embryo to the embryo of another species.

Mangold sliced a tiny segment of a salamander embryo and grafted it to the embryo of another creature. The graft took and what happened surprised Mangold and everyone else in the scientific world. The grafted patch formed an entire new body, a whole new body. Everything was there – the head, back, spiral cord – everything. Mangold's discovery was extraordinarily important. She had discovered that just a small slice of an embryo contains all the instructions necessary for the cells to build a body. This tiny piece of tissue was dubbed the Organizer.

Mangold's work won the Nobel Prize but unfortunately not until after her tragic death. She was a young woman when she died in a fire in her gasoline stove. In her place, Spemann - who owned the lab where Mangold did her work - won the Nobel Prize in Medicine in 1935. The announcement about the award referred to the Organizer as his discovery with no mention of Mangold.

Ted Daeschler

Ted Daeschler is a friend and close associate of Neil Shubin's. He studied paleontology in Philadelphia under Shubin's supervision. As a student of paleontology, Daeschler began collaborating with Shubin in 1993. Shubin liked working with him because he felt they made a good team. Shubin has "ants in his pants" and is always looking at the next step of a process. Daeschler's slow and steady pace and his patience tempered Shubin and forced him to give more thought to the current project so that nothing important was missed. They worked together on many expeditions in Pennsylvania where they found layers of rocks rich with fossils at the sites of road cuts. These layers of rocks were left exposed by powerful machinery that cut into boulders in order to build new highways. Daeschler is credited with discovering a shoulder bone that was dubbed "Hynerpeton" which is a reference to a creeping animal.

Aston Embry

Ashton Embry was the leader of the teams of Canadian geologists and paleobotanists on expeditions to the Canadian Arctic. He described the geology of the Devonian Age rocks in Canadian rocks. Shubin was intrigued when he read about Embry's findings; he found great similarities in the description of the Canadian rocks and the rocks that Shubin had been digging into in Pennsylvania. At was the impetus for Shubin to pack his gear and head to the Canadian Arctic.

Jenny Clack

Jenny Clack was a colleague of Shubin's at Cambridge University. She and other scientists discovered amphibian fossils in rocks on the east coast of Greenland that were estimated to be 365 million years old. The creature that Clack et al found was a very early creature that had limbs and is one of the world's earliest known tetrapod.

Dr. Farish A. Jenkins, Jr.

Dr. Farish A. Jenkins, Jr. was Shubin's graduate advisor at Harvard. Farish was a veteran field scientist who led multiple expeditions to Greenland over many years. Jenkins joined Shubin on an expedition to the Arctic where it was learned that the rocks were older than the fossil layers in Greenland and Pennsylvania where Shubin had focused his searches. Shubin was greatly appreciative of having Jenkins on the expedition for his experience and extensive knowledge of fossils and fossil research.

Jason Downs

Jason Downs was the graduate student on the Arctic Circle expedition that Shubin led when the "missing link" was discovered. Shubin had been eager for the expedition anticipating that they would discover the link between the fish and the amphibian – the first creature to have physical features of both that enabled it to survive in both worlds. It was the end of the trip and Shubin was ready to call it quits, disappointed that he hadn't achieved his goal when Jason Downs rushed in. He had found rocks apparently rich in fossils. The team eagerly investigated and ultimately found the "in-between" creature that Shubin had hoped to find.

Steve Gatesy

Steve Gatesy, a colleague of Shubin's, was on an expedition with Shubin on Ellesmere Island in Canada. He moved a rock and suddenly the snout of a flathead fish was staring right back at him. It was an important find and Steve spent the entire rest of the summer digging in the spot to try to locate the flathead's body. He worked meticulously, finding the rest of the fish tiny piece by tiny piece. Steve's work paid off. The recovery of the water-land transition fossil was one of the most important ever discovered.

Johann Goethe

Interest in the inner workings of man was not limited to scientists. The famous German writer Johann von Goethe stumbled across the cracked skull of a ram. Upon inspecting it closely he likened the brain to the organization of the body. He was among the first to make the connection between the head and body and that they are fundamentally the same plan.

Nicole King

Nichole King, a scientist working in the labs of the University of California at Berkeley, worked extensively with small organisms called choanoflagellates. From this work, King was able to establish definitively the difference between the DNA that instructs the building of single-cell and animals with heads genes.

Detlev Arendt

Detlev Arendt conducted extensive research on the eyes of a primitive worm called the polychaetes. He learned that the worm had had two methods of seeing. The worm used an eye to see and it used a segment of its nervous system that was able to gather light and therefore provide images. Arendt work was monumental. He proved that the vision process in polychaetes was a bridge between the vision of vertebrate and invertebrate animals.

Gurich and Glaessner

In the 1930s, German paleontologist Martin Gurich discovered flat, disk-like fossils in the region that is now Namibia. Fossils of the same species were also found in Australia. There was little excitement about them because they were viewed to be “new” fossils because of the rock layers they were found in. However, in the 1960s, Austrian paleontologist Martin Glaessner discovered that the rocks types in which Gurich and others found the disk-like fossils were actually up to twenty million years older than first believed. These creatures lived in what was the Precambrian era and fossil evidence proved that they were the first form of life that were multi-celled and had bodies. Gurich’s discovery that had been met with yawns was actually profound.

Gunnar Save-Soderbergh

Gunnar Save-Soderbergh was a Swedish paleontologist in the 1920s. His work led him to the fossil of a creature that was a link between fish and amphibian. He made his discovery in the fossil-rich eastern coast of Nova Scotia that was to lure many scientists including Neil Shubin in the years that followed. Save-Soderbergh’s first discover was called ichthyostega but it did not contain any history of amphibian-like limbs. However, his second discovery, the Acanthostega gunnari, had fingers and toes on its flipper-like limbs. That discovery was a phenomenal one.

Karl Ernst von Baer

Karl Ernst von Baer was a natural philosopher in the 1800s. He was supported in his research efforts by his wealthy friend Christian Pander. Von Baer focused his research on the study of embryos. He and Pander were amazed when they saw evidence that all organs in a chicken could be directly traced to of the three layers of tissue in the embryo. Von Baer compared his findings to a variety of species and the result was always the same. The organs in all species came from one of three layers of the embryo. These layers came to be known as the “germ” layers and the research of von Baer and Pander is still held as valid to this day.

Objects/Places

Arctic Circle

Neil Shubin focused a great deal of his focus on expeditions to the Arctic Circle. When he learned that the bones and fossils found in that region were much older than fossils he had been working with in Pennsylvania and the east coast of Nova Scotia, he made immediate plans to make an expedition there. His intuition paid off. It was there in the Arctic Circle that he and his colleagues discovered the creature that had elements of both fish and amphibian. It was later named the Tiktaalik and it proved the theory that many paleontologists and anatomists had held for years that there was truly a missing link – a creature that had features of fish as well as features of amphibians.

Greenland

The eastern coast of Greenland was another location that was rich in fossil finds. Shubin headed many expeditions to this region and discovered many fascinating fossils that helped to tell the story that he knew was there. The Greenland eastern coast had long been a haunt of scientists seeking fossil evidence of ancient life and its link to man. Gunnar Save-Soderbergh made two important discovers in the region. One was called the ichthyostega, which did not contain the secrets of the origin of limbs; the other was the Acanthostega gunnari which did have flipper-shaped limbs with fingers and toes.

Mt. Everest

It is Shubin's contention that every rock on earth tells a story. The rocks provide the history of the surrounding area and climates that are quite diverse from current-day conditions. He uses the example of Mt. Everest which has an altitude of over five miles at the apex. Rocks found on the North Face of the mountain rocks and sea shells from an ancient sea floor are plentiful. This is attributed to the undisputable fact that mountains fall and rise and climates go from cold to hot as continents move.

Field Paleontology

Fossils can be located with surprising ease and predictability if certain fundamental rules are followed. Before any planning can be done or predictions made, the scientists must target a specific fossil or fossils. With the geological knowledge of the planet that is available, the paleontologist will know where the rocks that are roughly the same age as the species being sought are most likely to be found. They will be selective about the type of rocks that are best for finding fossils and the locations where the top rocks are visible.

The Hand

Shubin felt an immediate connection to the first human hand he had to dissect. He had felt fairly distant and remote from his task until he saw the hand. It struck him that the hand holds mankind's complexity and humanity. He cites the 1822 book, "The Hand, Its Mechanism and Vital Endowments as Evincing Design," by Scottish surgeon. Bell believed the hand to be perfectly structured because of its complexity and how it was ideally arranged for man's use.

Collagen

Collagen is the most common protein in the human body. It represents 90 percent of all protein weight. Cells are well-ordered on outer bones. Molecules separate the cells and create collagen. This protein has unusual properties. Magnified 10,000 times, collagen has a rope-like appearance and consists of bundles of tiny molecular fibers. Just like a rope, collagen has its strength when pulled and, also just like rope, it loses strength when it is collapses and pushed together. Collagen fills the space between bones and between cartilage. Collagen is essential for bodybuilding and appears in abundance in all animals.

Tiktaalik

Tiktaalik was the name that the Intuits gave the creature that Shubin and his team found in the Arctic Circle. The fossil was the transformative creature that Shubin had been looking for. It had characteristics of both a fish and an amphibian. It was determined that the Tiktaalik hopped from puddle to puddle and had eyes on the top of his head so that it could look ahead for danger as opposed to a fish that had eyes on either side of its head to watch for prey.

ZPA

The zone of polarizing activity or ZPA was discovered by biologists in the 50s and 60s. ZPA is a small piece of tissue the controls bone development. When this minute patch is removed, all development stops. The patch contains instructions for the creation of the hand and other complicated parts of the body. Scientists at Harvard's biological lab discovered ZPA's genetic control.

Hox Genes

In the middle of each gene is a short DNA sequence that contains eight genes. These genes are known as Hox genes contain the body's organizational pattern. Hox genes control body proportions and when they are disturbed or malfunction a mutation will result. Versions of Hox genes are present in every animal that has a body.

The Recipe

The DNA provides instructions to the cells on how to develop. This “recipe” is what humans share with every other species. Shubin uses the example of food recipes passed down from one generation from another in families. The basic recipe is the same but changes and enhancements are made each time the recipe changes hands. The recipe that DNA provides to the cells for the body’s development has been the same since there was first life. But the recipe has been tweaked through the ages which has resulted in the diversity of the species.

Themes

Tenacity

Shubin's goal in finding and studying fossils was to discover what some consider a "missing link." He wanted to find fossil evidence of creatures that had features of both fish and amphibians. These creatures would help tell the story of how fish began to "sprout" new physical characteristics that enabled them to walk on solid ground. It was the challenge of a life time but Shubin committed himself to it.

To accomplish this goal, Shubin and his colleagues ultimately, decided to focus on three areas: the east cost of Greenland, eastern North America and the Canadian arctic with the latter being the most ideal. They had done their homework and found that these areas would be predictably the best sites to find the elusive fish/amphibian creature. It took Shubin and his team four expeditions to Ellesmere Island in the Arctic and six years to find their sweet spot.

The breakthrough came in 2000 when the expedition was nearly over and Shubin was profoundly disappointed that he hadn't found his creature. Dramatically, at this low point when Shubin was literally packing up, a graduate student on the dig found a spot that was overflowing with fossils. Shubin and team - now reinvigorated - were able to trace the rock layer that was the source of the bones the student found. It ultimately took two summers to uncover all the fossils in this spot. The majority of the fossils weren't closely related to living species.

In 2004, Shubin uncovered a patch of fish scales and a set of jaws that astounded him because the parts appeared to belong to a flat head fish. Another colleague uncovered a snout that also looked like it belonged to a flat head. The rest of the fish was uncovered and was a remarkable discovery; it was a water-to-land transition species. It had scales on its back and fins with webbing and had a flat head and neck like land mammals. Bones inside the fin correspond to arms and jointed wrists. Many elements of the species looked part fish and part amphibian. The team asked an Inuit tribe to suggest a name for the animals. They chose Tiktaalik which means large freshwater fish. There were multiple structural similarities between the new species and man. Shubin's dedication and tenacity finally paid off.

The Importance of Fossil Research

Having his readers understand how the body works and the important role that fossils have played in medical research is one of the main themes of "Your Inner Fish." The fundamental steps in building a body involves DNA and genes. Cells and molecules are also important in this development and in the continued health of the body. Paleontologists and anatomists have played a big role in attaining this knowledge which is vitally important to the medical world. The author describes what triggers the building

of a body and what parts are involved in making it all work. The fossils he and his colleagues, past and present, have found helped to understand man's evolution.

Fossil evidence has helped DNA research to understand the switching off of genes that differentiate bones in the hand and bones in the arm, etc. All genetic switching that defines bones is completed by the eighth week after conception. Biologists in the 50s and 60s discovered that a small piece of tissue controls the development of bones. If it's removed, development stops. A molecule or gene directs the development pattern. This patch of tissue is called the zone of polarizing activity or ZPA. This patch has the instructions to make a thumb and pinky and the fingers in between on a hand.

In 1993, Cliff Tabin's biological lab at Harvard discovered the genetic control for the ZPA. It was suspected that a molecule caused the development. Through experimentation, it was discovered that the pattern of gene activity causes the differentiation in cells. One gene was isolated as responsible for making the two ends of a fruit fly look completely different. It was dubbed the hedgehog gene. Scientists began looking for the hedgehog gene in other species. Scientists named the chicken hedgehog gene that they found the Sonic hedgehog. They discovered that the only cells that had gene activity were those in the ZPA tissue. They also discovered that the DNA instructions to build limbs and digits were the same in every creature with limbs.

The discoveries that paleontologists through their fossil work have made through the decades have been a great boon to medical research and to enable man to live a longer healthier life.

Women in Paleontology

Shubin cites the work of a number of women who have contributed to the advancements in paleontology and anatomology. In the 1920s, Hilde Mangold conducted research at the Spemann laboratories on the salamander embryo and discovered that grafting a minute portion of the embryo and grafting it on the embryo of another species created a whole new body. The tiny patch that Mangold grafted became known as the Organizer. Although In 1903 German embryologist Hans Spemann won the Nobel Prize in Medicine in 1935, it was the work of Mangold that was cited. She had died in an accident before her thesis was published. Mangold's work is considered to be the single most important advancement in the history of embryology.

In 1981, Linda Buck and her colleague Richard Axel discovered large number of cells that enable man to have a sense of smell and that fully three percent of all cells are focused on scent detection. Early man as well as other species relied on their sense of smell to find food and to evade predators. For their groundbreaking work, Buck and Axel won the Nobel Prize in 2004.

Jenny Clack who was a colleague of Shubin's and was instrumental in the discovery of amphibian fossils in Greenland. This creature had limbs and is one of the world's

earliest known tetrapods. It was an important discovery that greatly advanced the goal of paleontologists to discover the creatures that first crawled out of the ocean.

Nicole King of the University of California at Berkeley focused her research on the study of organisms known as choanoflagellates. From her vast experience in working with DNA, she knew that it was probable that these tiny organisms were the closest relatives of animals with bodies, placozoans and sponges. She suspected that their DNA would be similar to that used to make the human body. Nicole received support from the Human Genome Project. In the end she was able to define the difference between genes in single-celled microbes and those in animals with bodies. It was a great step forward in understanding the body building function of human DNA, cells and molecules.

Mildred Hoge was conducting research on fruit flies when she found one that had no eyes. This mutation is seen in other species including humans. Later research showed that “eyelessness” was caused by a gene, the Pax 6, in DNA structures that was found in all eyeless species including humans.

Women have helped to make great strides in the field of paleontology and in understanding the functioning of the human body.

Microbes and Man

The first comparison between animal and microbial genomes (single-celled) revealed that the molecular structure that includes cell adhesion and communication were not present. Nicole King of UC Berkeley, knowing that choanoflagellates are the closest microbes to animals. She believed that there were hidden genes that contained the recipe.

King found that most active genes in this species are also active in animals and are the genes that build bodies. Collagens which are the most predominant protein in the body are also present in the choanoflagellates as are the molecules that hold cells together. But they are used in different ways. A molecule similar to collagen is present on the surface of streptococcus bacteria. Other bacteria has proteoglycan molecules.

Nicole proved that the requisites to build bodies was present in microbes. There were many questions about the evolution of microbes. Why did it take 40 million years for animals with bodies and heads to appear? Why did bodies appear? Perhaps microbes started fighting, eating each other. One way to conquer an enemy is to grow more cells with more parts and get bigger than the enemy.

Why did the animals with bodies wait so long to evolve? The timing may have been wrong; maybe the world wasn’t ready for them. Earth was very low on oxygen for billions of years. A billion years ago there was an increase in oxygen in the atmosphere and it has remained at the same level since then. This is fact that is proven by ancient rocks. What is also indisputable is man’s connection to microbes.

Eyes and Ears

There is much focus in “Your Inner Fish” on the development of the eye and ears in various species. As always Shubin makes the link between the eyes and ears of humans and those of other species.

There are two types of eyes – the ones in invertebrates and the ones in vertebrates. It was thought that there was no connection between the two until in 2001 Detlev Arendt studied the eyes of a primitive worm, the polychaetes. They had two ways of seeing: an eye and part of the nervous system that gathered light. Arendt found that they each had elements of both kinds of animal photoreceptors. The eye was comprised of neurons and opsins like the eye of all invertebrates. The nervous system receptor had vertebrate opsins and the cellular structure although in a primitive form. The worm was a bridge between the vision of vertebrate and invertebrate animals.

Although worm eyes and human eyes look nothing alike, there are similarities. Mildred Hoge was conducting research on fruit flies when she found one that had no eyes. This mutation is seen in other species including humans. Later research showed that “eyelessness” was caused by a gene, the Pax 6, in DNA structures that was found in all eyeless species. Using the eyeless gene Walter Gehring and his team were able to create eyeless DNA and grow an eye on the antenna or back on any part of the fly’s body that they selected.

Shubin describes the ear as a Rube Goldberg contraption. Although it looks convoluted it is a masterpiece of efficiency. Although the building of the ear in humans is similar to that of other animals, Shubin makes a distinction here. The human and many mammals have three parts to their ears – the outer visible ear, the middle ear and inner ear while fish and other creatures have only two bones in their ears. He describes how the ears and eyes are connected inextricably through branches of nerves by using the example of a drunkard. An individual who drank too much becomes tipsy because the ethanol from the alcohol he consumes dilutes the natural fluid in the ears. The connection to the eye from the ear is obvious when imagining the red eyes of the drunk.

Shubin makes the case for the link between man and shark even though the shark has no ears. He describes the jaw bone in the shark that evolved in other creatures to eventually become the inner ear of the human and other mammals. And he’s got the fossil bones to prove it.

Styles

Structure

“Your Inner Fish” is laid out for the optimum understanding of complicated information much of which is unknown to the average person. The author, Neil Shubin, does not lay his work out in a chronological order because that tale would start some 500 million years ago. He beings this book by indicating that his work is his passion and explaining how a field paleontologist prepares for an expedition. The experienced paleontologist will predict where he can find the fossils he is looking for, how old the rocks will be and the kind of rock that he will find them in.

Shubin describes his triumph in finding the fossil of the Tiktaalik which is a creature that evolved from a fish that while retaining some characteristics of a fish also “grew” some amphibian features which allowed him to crawl to earth. Shubin then makes his case for the undeniable connection between all species that ever lived and man. He goes through the links that paleontologists found through the ages and how piece by piece they provided the evidence to support their theories of the connection. Shubin cites the work of many scientists who had gone before him and current colleagues of him who have all contributed to this long quest to find all the links and understand creation, life and man better.

Shubin includes many helpful graphics that represent the various points he makes about fossils and their meanings and importance. He provides a section with extensive notes and the resources that he used in writing this book.

Perspective

“Your Inner Fish” by Neil Shubin is told by the author in the first person. The book focuses on the connection between human beings and virtually every species that ever lived – including fish. Shubin’s voice in this work is one of authority. He is a veteran of hundred of digs for fossils that took place literally all over the world. Shubin is also provost of The Field Museum and assistant dean and professor of anatomy at the University of Chicago. He has a vast education in his field with degrees from Columbia, Harvard and the University of California at Berkeley.

Shubin relates his expeditions to the Arctic Circle, China, Nova Scotia and Arizona just to name a few. From these experiences, he enlightens the readers about the amazing fossil finds that he uncovered and most importantly what their significance and connection to man. He tells of the extraordinary effort and years of study and research that is undertaken after the discovery of new fossils. He describes in meticulous detail how scientists reach their conclusions about the fossils and their importance to the history of all living creatures that have inhabited Earth.

Shubin does not rely on his own experiences alone. He calls on the work of a plethora of other scientists who have gone before him. He cites the work of early paleontologists and anatomists and Nobel Prize winners who pioneered the way for modern molecular biologists and DNA supercomputers to catalogue fossils into groups that in essence comprise the family tree for mankind.

Tone

The overall tone of “Your Inner Fish” is informative and oftentimes technical in nature. However, Shubin brings a lightness and humor to much of his narrative which gives the reader a break from the intensity of the material. Shubin explains how the body works down to the molecular level which is quite heavy reading. He makes the connections between fossils that are literally millions and even billions of years old with man. Making the connection is a circuitous route and exhaustive for those readers who are not paleontologists. By providing some humorous anecdotes and witty narrative he lessens the unavoidable complexity and intensity of the material.

Shubin is not only an expert in the field of paleontology he has an emotional connection to his work that comes through the pages of technical speak to the reader. He expressed this sentiment through the book. He described when he dissected his first human cadaver that he kept himself distant and remote from what he was undertaking. He stayed calm and cool until the hand was sliced open. He felt a profound connection with mankind looking at the complexity and utility of the hand, a tool that separates man from most other species.

Even when describing some of the most profound complexities of the various species that he has studied, Shubin’s love of his science is not lost on the reader. It is obvious that Shubin considers his work to be more than just science – to him its art.

Quotes

Ancient fish bones can be a path to knowledge about who we are and how we got that way. We learn about our own bodies in seemingly bizarre places, ranging from the fossils of worms and fish recovered from rocks from around the world to the DNA in virtually every animal alive on earth today.
-- Shubin (Chapter 1 paragraph Page 3)

Importance: This quote captures the entire premise of “Finding Your Inner Fish” which is based on the author’s theory that man has a close relationship with fish.

The reason the wing of a bat and the arm of a human share a common skeletal pattern is because they shared a common ancestor.
-- Shubin (Chapter 2 paragraph Page 32)

Importance: Shubin paraphrased Charles Darwin in the above explanation for the similar elements in the bones of man and other species.

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.
-- Shubin (Chapter 2 paragraph Page 43)

Importance: The author points out that while fish are the ancestors of humans, humankind has far exceeded the abilities of these early species and that man is exceptional.

The biological processes that make these different organs are versions of the same thing. When you see these deep similarities among different organs and bodies, you begin to recognize that the adverse inhabitants of our world are just variations of a theme.
-- Shubin (Chapter 4 paragraph Page 80)

Importance: From Shubin’s research and study, he has observed the bones of so many creatures and has concluded that all species are the variation of the same thing. Looking inside the creatures and studying its bones and teeth, the same patterns and designs are seen over and over again no matter what the species and no matter how ancient the fossil is.

It was two nights before my anatomy final and I was in the labs at around two in the morning, memorizing the cranial nerves… So there I was, holding half of the head in each hand, tracing the twisted paths that the nerves take from our brains to the different muscles and sense organs inside.
-- Shubin (Chapter 5 paragraph Page 81)

Importance: Shubin adds a little black humor in describing the way he crammed for his final. Shubin had the ability to distance himself from working with cadavers for the sake of his ability to learn.

Today, many scientists consider Mangold's work to be the single most important experiment in the history of embryology.
-- Shubin (Chapter 6 paragraph Page 106)

Importance: Hilde Mangold had grafted a small patch of the embryo of a salamander onto the embryo of another species. An entire creature developed from this small patch which became known as the Organizer. It demonstrated that all the cells needed for creating an entire animal was contained in even a miniscule slice of the embryo.

All animals are the same but different. Like a cake recipe passed down from generation to generation – with enhancements to the cake in each – the recipe that builds our bodies has been passed down, and modified for eons. We may not look much like sea anemones and jellyfish, but the recipe that builds us is a more intricate version of the one that builds them.
-- Shubin (Chapter 6 paragraph Page 115)

Importance: Like all species, man is unique; however, the building of man's body from DNA instructions to the cells that build the body is, at its most basic level, the same all creatures on this planet.

When predators develop new ways of eating, prey develop new ways of avoiding that fate. This interplay may have led to the origin of our bodybuilding molecules.
-- Shubin (Chapter 7 paragraph Page 136)

Importance: Shubin poses the question: why did animals with bodies appear after 40 million years of microbes as the only form of life? Shubin is offering one theory that may answer the poser.

When you look into eyes, forget about romance, creation, and the windows into the soul. With their molecules, genes, and tissues derived from microbes, jellyfish, worms, and flies, you see an entire menagerie.
-- Shubin (Chapter 9 paragraph Page 157)

Importance: Shubin is making the argument that the history of the eye holds overwhelming evidence that there is a connection between all species including man to very early primitive worms.

The elegance of our connection to sharks and bony fish is revealed when we look inside our ears. Ears might seem an unlikely place for a human-shark connection, especially since sharks don't have ears. But the connection is there.
-- Shubin (Chapter 10 paragraph Page 159)

Importance: Shubin describes in great detail the surprising connection between sharks and man. In essence, the jaw bone of the shark evolved in transformative creatures to become the inner ear.

The biological ‘law of everything’ is that every living thing on the planet had parents.
-- Shubin (Chapter 11 paragraph Page 174)

Importance: Shubin provides this basic law that paleontology, developmental biology and genetics is based on. This statement also is the premise for the conclusions that he makes and that are based on his work with fossils that man is related to the species of all times from primitive microbes to fish, amphibians and mammals.

I can imagine few things more beautiful or intellectually profound than finding the basis for our humanity, and remedies for many of the ills we suffer, nestled inside some of the most humble creatures that have ever lived on our planet.
-- Shubin (Epilogue paragraph Page 201)

Importance: Shubin provides the emotional and intellectual argument for finding out about man’s past no matter where it leads us.

Topics for Discussion

Topic 1

What is the ordering of most rock layers that contain fossils? Describe the various elements which paleontologists use to “predict” where to dig for fossils.

Topic 2

What were the physical features of the Tiktaalik? What are some theories as to why animals that lived in the water made a transition to land?

Topic 3

Describe the work of Gunnar Save-Soderbergh. What did he discover, and what was information was missing from the creature? What was revealing about Save-Soderbergh’s second discovery?

Topic 4

While the DNA may provide the same instructions to build diverse cells, what creates different results in an entire creature? Why is this important to Shubin’s quest to find the link between water and land creatures?

Topic 5

What functions do the trigeminal nerve and the facial nerve have? Why do some branches of both appear in the same areas sometimes, like the ear for example?

Topic 6

What pattern is displayed by the body’s vertebrae? What does each vertebra represent? How is the organization of the head similar to the structure of the vertebrae?

Topic 7

How long have single-cell creatures versus animals with heads been living? What is the relevance of studying single-cell species like microbes in the furtherance of knowledge about the human body?

Topic 8

What was the significance of the discovery made by Linda Buck and Richard Axel in 1991? What assumptions did they make before they made their conclusions?

Topic 9

What distinguishes the basic structure of the human body from primitive creatures such as jellyfish and microbes? What are the basic architectures of the various groups of species?

Topic 10

Explain what modified descendants are. How can you see that in your own family tree and in the larger tree of mankind?