



## The New Science of Human Evolution

The new science of the brain and DNA is rewriting the history of human origins.

By Sharon Begley

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March 19, 2007 issue - Unlike teeth and skulls and other bones, hair is no match for the pitiless ravages of weather, geologic upheaval and time. So although skulls from millions of years ago testify to the increase in brain size as one species of human ancestor evolved into the next, and although the architecture of spine and hips shows when our ancestors first stood erect, the fossil record is silent on when they fully lost their body hair and replaced it with clothing. Which makes it fortunate that Mark Stoneking thought of lice.

Head lice live in the hair on the head. But body lice, a larger variety, are misnamed: they live in clothing. Head lice, as a species, go back millions of years, while body lice are a more recent arrival. Stoneking, an evolutionary anthropologist, had a hunch that he could calculate when body lice evolved from head lice by comparing the two varieties' DNA, which accumulates changes at a regular rate. (It's like calculating how long it took a typist to produce a document if you know he makes six typos per minute.) That fork in the louse's family tree, he and colleagues at Germany's Max Planck Institute for Evolutionary Anthropology concluded, occurred no more than 114,000 years ago. Since new kinds of creatures tend to appear when a new habitat does, that's when human ancestors must have lost their body hair for good—and made up for it with clothing that, besides keeping them warm, provided a home for the newly evolved louse.

If you had asked paleoanthropologists a generation ago what lice DNA might reveal about how we became human, they would have laughed you out of the room. But research into our origins and evolution has come a long way. Starting with the first discovery of a fossil suggesting that a different sort of human once lived on this planet—it was a Neanderthal skull, unearthed in a mine in Germany's Neander Valley in 1856—our species' genealogy was inferred from stones and bones. Fossils and tools testified to our ancestors' origins in Africa, the emergence of their ability to walk upright, the development of toolmaking and more. But now two new storytellers have begun speaking: DNA and brains.

The science of human evolution is undergoing its own revolution. Although we tend to see the march of species down through time as a single-file parade, with descendant succeeding ancestor in a neat line, the emerging science shows that the story of our species is far more complicated than Biblical literalists would have it—but also more complex than secular science suspected. By analyzing the DNA of today's humans as well as chimps and other species (even lice), scientists are zeroing in on turning points in evolution, such as when and how language and speech developed, and when our ancestors left Africa. DNA can even reveal how many pilgrims made that trek. At the new Hall of Human Origins at the American Museum of Natural History in New York, DNA gets equal billing with fossils. And by comparing the impressions that brains left on the inside of skulls, "paleoneurology" is documenting when structures that power the human mind arose, shedding light on how our ancestors lived and thought. Whether or not you believe the hand of God was guiding these changes, the discoveries are overturning longstanding ideas about how we became human.

Not that fossils are passé. new discoveries are pruning and reshaping humankind's family tree as radically as bonsai. The neat traditional model in which one species gave rise to another like Biblical "begats" has been replaced by a profusion of branches, representing species that lived at the same time as our direct ancestors but whose lines died out. It's like discovering that your great-great-grandfather was not an only child as you'd thought, but had a number of siblings who, for unknown reasons, left no descendants. New research also shows that "progress" and "human evolution" are only occasional partners. More than once in human prehistory, evolution created a modern trait such as a face without jutting, apelike brows and jaws, only to let it go extinct, before trying again a few million years later. Our species' travels through time proceeded in fits and starts, with long periods when "nothing much happened," punctuated by bursts of dizzying change, says paleontologist Ian Tattersall, co-curator of the American Museum's new hall.

As its exhibits show, humankind's roots are sunk deep in the East African savanna. There, the last creature ancestral to humans as well as chimps—our closest living cousins—lived, standing at a fork in the family tree as momentous as it is contentious. Fossils never resolved when the lineages split. DNA might. Human DNA

and chimp DNA differ by no more than 1.2 percent, and DNA changes at a fairly regular rate. That lets scientists use this rate to calibrate a "molecular clock" whose tick-tocks measure how long ago a genetic change occurred. The fact that the DNA of living chimps and humans differ by about 35 million chemical "letters," for instance, implies that the two lineages split 5 million to 6 million years ago. That fits with the discovery that Earth became cruelly colder and drier 6.5 million years ago, just the sort of climate change that coaxes new species into being. The apes that stayed in the forests hardly changed; they are the ancestors of today's chimps. Those that ventured into the newly formed habitat of dry grasslands had taken the first steps toward becoming human.

Now the contentious part. In 2001, a team digging in Chad unearthed what it claimed was the oldest fossil of an ancestor of humans but not chimps. If so, it must have lived *after* the two lineages split. Trouble was, *Sahelanthropus tchadensis* (nicknamed Toumai, the local word for "child") lived close to 7 million years ago. The genetic data, pointing to a human-chimp split at least 1 million years later, suggest that Toumai is not the ur-hominid—the first creature ancestral only to human and not our chimp cousins—after all.

If Toumai is not our ancestor, what is he doing with such a humanlike face and teeth, which look like those of species 5 million years his junior? "A 7 million-year-old hominid should be just starting to look like a hominid, not have a trait you see so much later in the fossil record," says paleoanthropologist Bernard Wood of George Washington University. Even if he is not our ancestor, Toumai is valuable because he undermines the "begat" model of human evolution—that Toumai begat *Australopithecus* who begat *Homo habilis* who begat *Homo erectus* who begat *Homo sapiens*. That model assumes that each biological innovation, whether bipedality or a large brain or any other, evolved only once and stuck.

Instead, evolution played Mr. Potato Head, putting different combinations of features on ancient hominids then letting them vanish until a later species evolved them. "Similar traits evolved more than once, which means you can't use them as gold-plated evidence that one fossil is descended from another or that having an advanced trait means a fossil was a direct ancestor of modern humans," says Wood. "Lots of branches in the human family tree don't make it to the surface."

In fact, starting 4 million years ago half a dozen hominids belonging to the genus *Australopithecus* called Africa home. Best-known for the fossil named Lucy, which was discovered in 1974, *Australopithecus afarensis* had apelike features such as a large jaw and jutting face, and probably scrambled up trees for safety and shelter. But she also strode the grasslands erect, a hallmark of modern humans. Footprints preserved in volcanic ash 3.6 million years old are mute testimony to how one larger *afarensis* and a smaller companion—woman and mate, or parent and child—walked across a plain in what is now Tanzania.

What triggered this abrupt change—what set us on the road to becoming fully human—has long stumped experts. Where stones and bones were of little help, however, genes and brains have begun to speak. Last summer scientists discovered a gene called HAR1 (for human accelerated region) that is present in animals from chickens to chimps to people. It had changed in only two of its 118 chemical "letters" from 310 million years ago (when the lineages of chickens and chimps split) to 5 million years ago. But 18 letters changed in the (relative) blink of an eye since the human lineage split from chimps', Katherine Pollard of the University of California, Davis, and colleagues reported. That high rate of change is a sign of a gene whose evolution keeps conferring advantages on those who carry it, perhaps starting with *Australopithecus*.

The brain, more than any other organ, may have reaped those genetic advantages. HAR1 reaches a peak of activity from the seventh to ninth week of gestation in humans, apparently spurring brain growth. And it is plentiful in cells that create the six layers of neurons in the human cortex. "HAR1 is present in neurons that play a role in the geometry and layout of the cortex," says Pollard. It likely helped the cortexes of our ancestors develop the elaborate folds characteristic of a complex brain.

Besides making brain structure more complex, genetic change also advanced the brain's chemistry. In 2005, Matthew Rockman of Duke University and colleagues discovered that a gene called PDYN began accumulating changes 7 million years ago, soon after our oldest direct ancestor appeared. This gene regulates production of a molecule called prodynorphin, which is like the brain's soup stock: depending on what other ingredients are added, it can change into neurochemicals that underlie perception, behavior or memory. "Fossils can tell us a lot, but it is genomes that tell us what was involved in making language possible and in making brains the way they are today," says Rob DeSalle, co-curator of the American Museum's new hall.

It surely took more than prodynorphin's magic to modernize a brain and thus jump-start the creation of

new species. To find what else made us human, scientists led by neurogeneticist Daniel Geschwind of UCLA are examining which combinations of genes are active in the cortex, the seat of higher thinking, of chimps and people. Among the genes turned to "high" in people, they reported last year, are those that influence how fast electrical signals jump from neuron to neuron and therefore how fast the brain can process information, those that enhance connections between the cells and thus learning and memory, and those that promote brain growth. This pattern of gene activity, it appears, began emerging when Australo-pithecus species did.

And it helps explain why Lucy's kind were the way they were. Afarensis women and men stood three to five feet tall and weighed 60 to 100 pounds. They had small teeth good for fruits and nuts, but not meat. (The available prey was enough to make one a confirmed vegetarian: hyenas the size of bears, saber-toothed cats and other mega-reptiles and raptors.) That suggests that early humans were more often prey than predators, says anthropologist Robert Sussman of Washington University, coauthor of the 2005 book "Man the Hunted." The evidence is as stark as the many fossil skulls containing holes made by big cats and talon marks from raptors.

The realization that early humans were the hunted and not hunters has upended traditional ideas about what it takes for a species to thrive. For decades the reigning view had been that hunting prowess and the ability to vanquish competitors was the key to our ancestors' evolutionary success (an idea fostered, critics now say, by the male domination of anthropology during most of the 20th century). But prey species do not owe their survival to anything of the sort, argues Sussman. Instead, they rely on their wits and, especially, social skills to survive. Being hunted brought evolutionary pressure on our ancestors to cooperate and live in cohesive groups. That, more than aggression and warfare, is our evolutionary legacy.

Both genetics and paleoneurology back that up. A hormone called oxytocin, best-known for inducing labor and lactation in women, also operates in the brain (of both sexes). There, it promotes trust during interactions with other people, and thus the cooperative behavior that lets groups of people live together for the common good. By comparing the chimp genome with the human, scientists infer that oxytocin existed in the ancestor of both. But it has undergone changes since then, perhaps in how strongly the brain responds to it and in how much is produced. The research is still underway, but one possibility is that the changes occurred around the time our ancestors settled into a system based on enduring bonds between men and women, about 1.7 million years ago.

That was a formula for success, and one that may have also left a mark on the brain. Besides revealing the size of a brain, paleoneurology examines impressions of surface features that the brain leaves on the inside of the skull. That yields clues to its organization. Comparing the shapes of the brains of two hominids that lived 2.5 million years ago, *Australopithecus africanus* and *Paranthropus*, scientists find major differences in the shape of the frontal lobe, which controls higher cognition. "Paranthropus has a teardrop shape, whereas africanus is more squared off, and africanus has a swooping down on the bottom where Paranthropus is sort of peaked," says Dean Falk of Florida State University. That configuration suggests that africanus had a better-developed region called area 10, which plays a key role in decision-making, taking initiative and advance planning. It may be why africanus evolved while Paranthropus came to a dead end.

Paleoneurology promises to do what simplistic studies of ancient brains—which asked only how big they were—could not: explain our ancestors' great leaps forward. About 2.5 million years ago a new genus, *Homo habilis*, appeared in Africa. Discovered by the legendary Louis and Mary Leakey, habilis was the first hominid with a brain bigger than a chimp's, and was the first toolmaker: stone tools—sharp flakes of rock—appeared when habilis did. Their direct descendant, *Homo erectus*, took an equally momentous step: venturing beyond Africa. In the Republic of Georgia at a site called Dmanisi, scientists have unearthed 1.8 million-year-old fossils of erectus, "the first outpost we know of beyond Africa," says G. Philip Rightmire of Binghamton University. "It looks like these people got out and materialized everywhere in Eurasia," showing up as Java man and Peking man, among others. (None of the original fossils of Peking man survived World War II. Packed for shipment to the United States for safekeeping, they disappeared in transit; only casts remain.) Ancient humans didn't just walk: they reached Australia 60,000 years ago, across miles of open ocean.

Erectus shows that brain size is too crude a measure of a species' talents. At Dmanisi, the brains range from 600 to 770 cubic centimeters, comparable to the more primitive habilis. But while erectus did not distinguish themselves in brain size, brain structure is more telling. They were the first of our ancestors to have an asymmetric brain, as modern humans do; Australopithecus species do not. Asymmetry is a mark of increasing specialization and therefore complex cognitive ability. Erectus used it to, among other things,

discover and tame fire. What they did not use it for is technology. Tools found with the Dmanisi fossils include cutting flakes, rock "cores" from which flakes were made and a chopper, all primitive even for their time. "The old idea that you needed a master's degree in stone tools to leave Africa is crazy," says Bernard Wood.

Although erectus spread across Eurasia between 2 million and 1 million years ago, DNA makes clear that the species was almost certainly a dead end and not our ancestor, as some scientists had argued. According to this idea, groups of erectus scattered across the Old World all accrued the same mutations and underwent the same natural selection that led to Homo sapiens. The Y chromosome begs to differ. The Y is passed intact from father to son; in that sense, it's like a last name and so can be used to trace ancestries. But like surnames that got Anglicized at Ellis Island, sometimes a Y changes, with the altered version being passed to all male descendants. Peter Underhill, a molecular anthropologist at Stanford University, tracked 160 such changes in the Y's of 1,062 men from 21 populations across the world. Applying the molecular-clock technique, he concludes that the most recent common ancestor of all men alive today lived 89,000 years ago in Africa. The first modern humans—and therefore, unlike the earlier wave of Homo erectus into Asia a million years ago, the ancestors of everyone today—departed Africa about 66,000 years ago.

These pilgrims were strikingly few. From the amount of variation in Y chromosomes today, population geneticists infer how many individuals were in this "founder" population. The best estimate: 2,000 men. Assuming an equal number of women, only 4,000 brave souls ventured forth from Africa. We are their descendants.

A curious thing about early Homo species is that they looked quite human early on. "By 600,000 years ago everyone had a big brain, and by 200,000 years ago people in Africa looked like modern humans," says archeologist Richard Klein of Stanford. "But there was no representational art, no figurines, no jewelry until 50,000 years ago. Some kind of cognitive advance was required, probably in language or working memory. But since size hardly changed, the brain change that produced behaviorally modern humans must have been in structure."

The source of such structural changes must come, like every aspect of our physiology, from genes. Combing the genome for genes that emerged just when language, art, culture and other products of higher intelligence did, researchers have found three with the right timing.

The first, called FOXP2, plays a role in human speech and language, but it must do something else in other species, because the decidedly nonverbal mouse has a version of it. Using the standard molecular-clock tactic, Svante Paabo and colleagues at the Max Planck Institute estimate that the human version of FOXP2 appeared less than 200,000 years ago—about when anatomically modern humans stepped onto the world stage—and maybe as recently as 50,000. If so, then it is only humans as modern as those in the last diaspora out of Africa who developed advanced, spoken language. Another gene with interesting timing is microcephalin, which affects brain size. It carries a time stamp of 37,000 years ago, again when symbolic thinking was taking hold in our most recent ancestors. The third, called ASPM and also involved in brain size, clocks in at 5,800 years. That was just before people established the first cities in the Near East and is well after Homo sapiens attained their modern form. It therefore suggests that we are still evolving.

The fossils have not finished speaking, of course. These countless postcards from the past surely still lie en-cased in the rocks of the Old World. But now, as ancient DNA and gray matter give up their secrets, they are adding life to the age-old quest to understand where humankind came from and how we got here.

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