How Mitochondrial Eve Connected all of Humanity and Rewrote Human Evolution

By: Alasdair Wilkins

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This month marks the twenty-fifth anniversary of the discovery of Mitochondrial Eve, the common ancestor of every human alive today. Here's everything you need to know about why the mother of humanity is so important.

Top image via Smithsonian Institution.

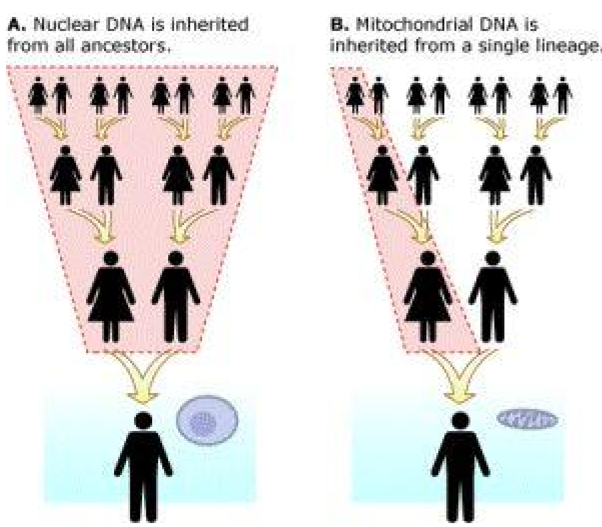
The Discovery of Mitochondrial Eve

In January 1987, Rebecca Cann, Mark Stoneking, and Allan Wilson published a paper in *Nature* that dropped a bombshell of our understanding of human evolution. Until then, the prevailing theory held that different groups of humans had evolved separately in different regions, beginning about two million years ago. Their groundbreaking work revealed all humans carried mitochondrial DNA in their cells that dated back to a single woman who had lived just 200,000 years ago. This woman was dubbed Mitochondrial Eve.

Though their research was initially met with tremendous controversy, the death knell of the multiregional hypothesis had already been struck. The idea here was that our predecessor *Homo erectus* had left Africa two million years ago and spread out around the entire world. Then, these different populations adapted to their new environments by evolving into *Homo sapiens*, although constant gene flow and interbreeding between these different populations meant that everyone remained part of the same species. This model was seen as the best way to explain all the *Homo erectus* fossils found throughout Africa, Eurasia, and Australia.

The discovery of Mitochondrial Eve gave crucial support to the Recent African Origin model, which held that modern humans only evolved once, most likely in East Africa, somewhere between 150,000 and 200,000 years ago. All older fossils discovered elsewhere represented hominid lineages that had since gone extinct. And while we've recently seen some strange fossil findings that could complicate the picture yet again, the basic tenets of the Recent African Origin model are now well-established.

So how did Mitochondrial Eve manage to rewrite the entire story of human evolution? For that matter, what exactly *is* Mitochondrial Eve? Unlike her biblical namesake, she wasn't the only woman on Earth. In a sense, she's just a quirk of statistics. But if that's the case, then she's easily the most important quirk of statistics who ever lived.



What Mitochondrial Eve Really Means

In sexual reproduction, a person will only pass on half of his or her genes, and their contribution to ensuing generations will continually divide by half. After a thousand years, any one ancestor's genetic contribution will drop to effectively nothing. That actually means that the most recent common ancestor of all human beings, or MRCA, who lived anywhere from 2,000 to 40,000 years ago, is more a statistical curiosity than a genetic benefactor, and he or she is related to all of us today in only the most technical of senses.

In order to find a common ancestor whose genetics *have* passed on, we need to look for things that are passed down from generation to generation with little or no alteration. Both genders pass along one thing that is unchanged during sexual reproduction. For women, this is the mitochondrial DNA, which is a distinct subset of genetic material found not in the cell nucleus but rather in the mitochondria, the power plants of the cell.

In most species, including humans, the female egg cells completely destroy the mitochondria in the male sperm cell shortly after fertilization, leaving only the female mitochondria behind. This is where we get the term "Mitochondrial Eve", made popular on shows like the *Battlestar Galactica* reboot. This individual passed down her mitochondria relatively unchanged to every human alive today, and all females will continue to pass down her mitochondria indefinitely.

By tracing the subtle mutations to mitochondrial DNA that have accumulated over the millennia, we can figure out which groups are most closely related, and ultimately fix the existence of Mitochondrial Eve to a fairly specific time in the past, which is currently estimated at about 200,000 years ago. That pretty much rules out the idea of multiple origins for humanity — otherwise Mitochondrial Eve would have to date back a couple million years, and mitochondrial analysis shows that that simply isn't the case.
It's worth noting that Mitochondrial Eve would not have been exceptional during her own life. She certainly wasn't the *only* woman alive at the time, merely the only one who can trace descent to *everyone* alive right now. All the other women alive at the same time as her either left no living descendants or are only related to some smaller subset of the people alive today.

The Great Ancestor Shortage

While Mitochondrial Eve has been the most scientifically important of our common ancestors, she isn't the only one, and she is far from the most recent. Indeed, we don't have to go very far up our family trees to discover just how interrelated we really are. It's a question of basic mathematics — there simply aren't enough ancestors to go around. To understand what I mean, let's say you were born in 1975, your parents were both born in 1950, your four grandparents were born in 1925, your eight great-grandparents in 1900, and so on. In other words, your number of ancestors doubles every 25 years further back in time you go.

If you take this back just 1,000 years, simple math demands that you have well over 500 billion ancestors in a single generation. Considering there's fewer than seven billion people on this planet - and even *that* is far, far more than any other point in human history - there's something seriously wrong here. The solution, of course, is that you don't have 500 billion *distinct* ancestors, but rather a much, much smaller number of ancestors reappear over and over and over again in your family tree.

Figuring out just how many of your ancestors in a given generation were "real" and how many were duplicates can make for some fascinating statistics:

> *Demographer Kenneth Wachtel estimates that the typical English child born in 1947 would have had around 60,000 theoretical ancestors at the time of the discovery of America. Of this number, 95 percent would have been different individuals and 5 percent duplicates. (Sounds like Invasion of the Body Snatchers, but you know what I mean.) Twenty generations back the kid would have 600,000 ancestors, one-third of which would be duplicates. At the time of the Black Death, he'd have had 3.5 million - 30 percent real, 70 percent duplicates. The maximum number of "real" ancestors occurs around 1200 AD - 2 million, some 80 percent of the population of England.*

While we don't really have 500 billion different ancestors, we can still look at the reverse of that idea: is there a single common ancestor that every person on Earth shares? As we know with

Mitochondrial Eve, that answer is a resounding "yes" - but let's now take a look at the Most Recent Common Ancestor, or MRCA. The name says it all, really - this is simply the most recent person who, through any and all genetic lines, can be connected to every single person alive today.

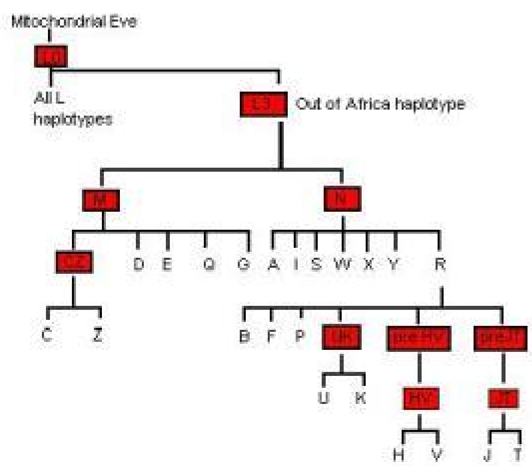
While it's fun to imagine a very small band of humans from which all humans are descended, the MRCA lived long, *long* after any such population bottleneck. Even more so than Mitochondrial Eve, the MRCA is the ultimate quirk of statistics, a random individual who happens to be the latest person who connects to everyone. In fact, depending on who you believe, the MRCA might have lived just 2,000 years ago, so this definitely has nothing to do with being the world's only human.

Shifting Dates

What's particularly fascinating about this is that we in the present day can actually change who our most recent common ancestor was. After all, the estimate that the MRCA lived only two or three millennia ago, long after humans became isolated on far distant continents, only works because of the globalization of the last 500 years. The theory is that enough European explorers intermarried with the various indigenous populations of the places they colonized so that, over time, even the most isolated groups become linked into the overall family tree.

This is a controversial theory, particularly since there are still thought to be a handful of uncontacted groups in South America and southwest Asia. If these peoples - each group of which only numbers about two hundred or so - really have remained completely cut off from other humans for millennia, then that would force the most recent common ancestor back to the Upper Paleolithic, anywhere from 40,000 to 10,000 years ago.

We can at least say this: in 2011, it's possible but not proven that the MRCA dates back to a surprisingly recent date, anywhere from 8,000 to 2,000 years ago. In 1511, before European exploration had really begun in earnest, the MRCA was still unquestionably an individual who lived in the Upper Paleolithic. And, by 2511, the current trends in globalization suggest that *everyone* will definitely share a recent MRCA...and one that gets more recent with each passing generation as more and more lineages mix.



Y-chromosomal Adam

Finally, let's take a look at Mitochondrial Eve's lesser-known male counterpart. The science here is simple enough - since only men have a Y-chromosome, fathers pass it on more or less unchanged to their sons, which allows geneticists to trace patrilineal descent in much the same way that mitochondrial DNA allows us to trace matrilineal descent. Intriguingly, genetic evidence suggests that Y-chromosomal Adam lived about 90,000 to 60,000 years ago, long after Mitochondrial Eve.

Why is everyone's male ancestor so much more recent than everyone's female ancestor? It's all down to breeding patterns. In Paleolithic times, the general rule was that any fertile woman could expect to have a certain number of offspring, and this was fairly evenly distributed. Paleolithic men, on the other hand, might father many children by multiple mothers, or they might fail to father any children at all. Of course, that's something of an oversimplification — anything describing tens of thousands of years of human activity inevitably will be — but it explains why our male ancestors cluster together more and why our common patrilineal ancestor is so much more recent than his matrilineal counterpart.

All of this speaks to how small our planet really is — and, indeed, always has been — a powerful reminder of how little real difference there is between us all. In fact, that's probably the greatest legacy of Mitochondrial Eve, 25 years on. Instead of lots of different protohumans evolving separately over millions of years, the story of humanity is much shorter, more elegant, and more interconnected than scientists had once ever imagined. While it's generally dicey to mix science with sentiment, I've got to say — that's a story of human evolution I can get behind.

Indeed, as Joseph T. Chang, Douglas L.T. Rhode, and Steve Olson observe in their 2004 paper on the MRCA, we're all shocking interrelated, and getting more so all the time:

> *"No matter the languages we speak or the color of our skin, we share ancestors who planted rice on the banks of the Yangtze, who first domesticated horses on the steppes of the Ukraine, who hunted giant sloths in the forests of North and South America, and who labored to build the Great Pyramid of Khufu. [And] within two thousand years, it is likely that everyone on earth will be descended from most of us."*

Further explanation:

Say there are 20,000 modern humans on planet earth on the day mt Eve is born. Eve has a wonderful easy life and gives birth to eight girls all of whom survive to have children. Eve's next door neighbor Lilith has five kids, none of whom make it through puberty. Their other neighbor Betty has four boys and *while she passes on her mitochondrial DNA to them, they don't pass it on to their kids. End of the line for Betty and Lilith. Eve's other neighbor Wilma has three daughters who survive to have kids. The first has only boys who survive. The second and third both have daughters. So you'd think, hey there are two options: either Eve or Wilma. But over time Wilma's lineage either dies out completely or becomes entirely male preventing mitochondrial DNA from passing one. Let's say each of Eve's eight girls has five girls who reach adulthood and let's say each of those 40 girls has three daughters who reach adulthood. But humans haven't drastically overcome their replacement rate, so there's still maybe 22,000 people on earth. But Eve's daughters already make up 5% of the earth's population. Say this one family line gets lucky for eight generations: mostly daughters, mostly making it to adulthood, while the total population remains relatively low. At some point Eve's DNA has reached a critical mass: they make up 50 percent of women who can bare children while the other 50 percent is made up of multiple other DNA lines. Each time one of those 50% has a boy or has a child die young it may be the end of their DNA line. But if Eve's group makes up the other 50% they can not only afford to take some losses in the genetic lottery, everyone else's losses increase their share. At some point it's a downhill race with each subsequent generation ceding more ground to Eve's family until they were the only one's left.*

Even though I completely fudged the numbers, that's basically what happened: one family that was lousy with girls kept being so. The population didn't grow faster than the proportion of women that were related to this single family until all women (and then the next generation, all people) were related to Eve.

Also, it's worth remembering that prior to the agriculture revolution women's genetics seem to have traveled more. Perhaps women were freer to go wherever they wanted or brides traded across long distances, but female DNA seemed to travel farther faster than male DNA.