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WHAT EVOLUTION REALLY TELLS US
ABOUT SEX, DIET, AND
HOW WE LIVE

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The Perfect Paleofantasy Diet

MILK

People are often passionate about dairy products. As I mentioned in the Introduction, my friend Oddný Ósk Sverrisdóttir and her colleagues are busy searching through the bones of long-dead Europeans for clues to the likelihood that milk was a part of their diet. And arguments about milk being a "natural" or even a healthy food abound. The website Notmilk.com, which, as the name suggests, is not a fan of the substance, intones, "Human milk is for human infants, dogs' milk is for pups, cows' milk is for calves, cats' milk is for kittens, and so forth. Clearly, this is the way nature intends it."[1] It also contains instructions on how to "detox" from dairy, promising that after just one week of abstention, "one gallon of mucus will be expelled from your kidneys, spleen, pancreas, and other internal organs,"[2] followed by an improvement in your sleep, mood, and sex life, though presumably the mucus needs to be dealt with before this rejuvenation can be realized.

This rather unappetizing image aside, and recognizing the considerable disagreement by medical experts with such an extreme view, it is undeniable that milk consumption is a novelty in human existence. Even today, the majority of people on Earth do not consume dairy foods after childhood. And that is just the way

it should be, according to some readers of the *New York Times Well* blog and the website Cavemanforum.com. One of the former stated:

> Cheese is dairy. People aren't designed to eat dairy. Baby cows are. Simply put, it's a large reason people are obese and suffer western diseases like diabetes, heart disease, cancer and autoimmune diseases. There's a HUGE body of research behind the evils of cow proteins. Cow milk (and the cheese made from it) is designed to make baby cows fat quickly. Guess what it does to humans?[3]

On the forum, one response to the question "What's wrong with cheese?" was:

> I don't eat it because it's not paleo, as Paleo Dude says. The basic idea behind paleo is that we are adapted to what we ate during the 2,000,000 years of the paleolithic, so those things are safe. Anything else is questionable.[4]

It is precisely this novelty that makes milk, or more accurately, the ability to digest it, the poster child for rapid evolution in humans. We understand more about how this ability came about, what it means at a genetic level, and what its consequences have been, than we do about virtually any other change in the human genome.

What's more, the use of dairy as a food source is an illustration of how genes and human cultural activities can influence each other. This gene-culture interaction is also huge: it means not just that humans have evolved, and recently (impressive though that is) or that culture has changed through time (though that, too, occurs), but that both have been altered, one by the other, in a tight coevolutionary spiral that may be continuing right now.

Finally, understanding the evolution of lactose digestion requires the use of every tool that science possesses. We use computer models that treat people and their genes as bits of code in a hypothetical universe. We use the dusty particles of DNA that Sverrisdóttir and her coworkers gouge from bleached bones, as well as the juicier samples extracted from modern Finns and African nomads. We even use microscopic bits of butterfat scraped from shards of ceramic vessels that were used to store milk and cheese thousands of years ago. Who knows—maybe someone millennia from now will be delving into the discarded Häagen-Dazs cartons of our time to find out more about our genes.

The problem

Unlike some animals that specialize in only one or a few foods—for example, anteaters that eat just their eponymous insects or koalas that monotonously munch eucalyptus—human beings can eat and digest a wide variety of foods, both plant and animal. We cannot eat everything, of course; we lack the bacteria and other microorganisms necessary to break down the cellulose in grass and many other plants, which means that we cannot survive by grazing like cattle. But many other foods are fair game.

At first glance, milk would seem to pose little difficulty for omnivores like us. After all, milk, or the ability to produce it, is what defines us as mammals, along with mice, whales, goats, armadillos, and the rest of the variously furred or haired crew. Our group got its name back in 1758, when Carolus Linnaeus, the Swede famous for developing the double-barreled system of Latin names for each organism still in use today, decided to make "the female mammae the icon of that class," as historian Londa Schiebinger puts it.[5] Schiebinger points out the gender politics evident in Linnaeus's choice, observing that no other group was distinguished by female

reproductive parts, but be that as it may, milk is essential to the young mammal's life. Lactation, the production of milk, provides mammalian offspring with nutrition and essential components of the immune system. Even the monotremes, those oddball mammalian egg layers like the echidna and platypus, rely on milk, with the youngsters lapping it up from specialized skin on their mothers' bellies. We could, with equal justification, have been dubbed "lactimals."

All good things must come to an end, however, and so it is with milk consumption, or at least so it is for all mammals other than humans. Each species has its own signature blend of components such as protein, fat, and calories geared to the growth schedule of the young animal consuming it. Cow's milk is higher in protein but lower in fat than human milk, though it contains nearly the same number of calories. Whales and seals are famous for the high fat content of their milk, essential to the rapid growth of their young in cold environments. A colleague of mine who studied seals in the Arctic says that the milk in some species is so thick with butterfat that it resembles toothpaste squeezed out of a tube into the mouths of the hungry pups. Surprisingly, mouse milk is quite high in fat and calories, though not on a par with the milk of marine mammals; a cup of mouse milk, assuming you had the patience to obtain it, would contain over 400 calories, more than two and a half times the number in cow's milk.[6]

Despite these differences, nearly all milk, regardless of the species from which it originates, contains a type of sugar called lactose. Digesting lactose—that is, breaking it down in the small intestine so that it can be used by the body—requires an enzyme called lactase. The ability to produce lactase is genetically controlled, and that ability is present, with extremely rare exceptions, in all mammals at birth. The lactase molecule spends its time tucked into the small intestine, able to encounter lactose as it tumbles by from dairy-rich meals. (A small percentage of babies are allergic to milk at birth, but this allergy is a reaction to the protein in milk, not its sugar, and it is distinct from lactose intolerance.) A funny thing happens on the way to adolescence, however: lactase production in all non-human mammals, and in most humans as well, grinds to a near halt sometime soon after weaning. Most adults possess only about 10 percent of an infant's lactose-digesting ability. Why lactase stops being produced is an interesting question that has received, at least in my opinion, too little consideration. Saying "it's not needed anymore" isn't really satisfying, since of course organisms retain many characteristics that aren't necessary, from human appendices to the tiny vestigial legs in whale skeletons.

Whatever the reason for lactase's usual disappearance, consuming lactose after the enzyme is no longer active often has unpleasant gastrointestinal consequences. If it is not broken down, lactose passes into the large intestine, which contains the rich stew of microorganisms we rely on for help with digesting many of our foods. When these microbes encounter lactose, they cheerfully ferment it too, causing the production of methane and hydrogen gas. We always produce some of this gas, but in large amounts in the lower gastrointestinal tract, it, along with other by-products of the bacterial activity, causes bloating, abdominal cramps, and diarrhea.

Some drugs and parasites, such as the protozoan *Giardia*, may damage the intestine so that it no longer digests lactose, but the more usual cause of lactose intolerance is the absence of the enzyme. A common test for lactose intolerance measures the amount of hydrogen gas exhaled in the breath after consumption of milk products; in people who don't produce lactase, the levels are higher. Even those without lactase can often consume small amounts of lactose, and fermented dairy products like cheese and yogurt are usually tolerated reasonably well, since the lactose has already been partially digested in such foods. But generally speaking, if you lack lactase, dairy products are not a desirable part of the menu.

The solution

Despite these difficulties, many people can continue to consume dairy products throughout their lives. Why is that? The Greeks and Romans noticed that adults differ in their ability to digest dairy products, but not until the last half of the twentieth century did people recognize patterns of lactose tolerance that suggested it was genetically based. In people who can tolerate milk as adults, the gene responsible for producing lactase continues to be active because of a mutation in another genetic region that ordinarily curtails the enzyme. By the 1970s, scientists had determined that lactase persistence is a dominant trait, meaning that only one copy of the gene controlling it, from just one parent, is needed for a child to exhibit the ability to digest dairy. (If it were a recessive trait, in contrast, a child would need to inherit two copies of the gene.) The exact nature of the molecules governing lactase persistence was identified in the early part of the twenty-first century, although work on the details of the alteration continues.

Initially, lactase persistence was assumed to be the "normal" state, with the lactose-intolerant an unfortunately flatulent few. But as more people around the world were surveyed, it became clear that the ability to digest dairy products in adulthood is prevalent in only certain parts of the world: northern Europe, particularly Scandinavia, and parts of Africa and the Middle East. About 35 percent of all the people in the world show lactase persistence, and they are clustered in only a few places.

The distribution in Africa is particularly interesting, because there, ethnic groups that live virtually side by side can have strikingly different proportions of individuals with lactase persistence. In the Sudan, for example, lactase persistence is seen in less than 30 percent of the Nilotic peoples but occurs in over 80 percent of the nomadic Beja. The Bedouin of the Middle East are also much more likely to be able to consume dairy than are their non-Bedouin counterparts in the same regions. What is responsible for the variation? Rapid evolution.

Cows first

To understand the evolution of lactase persistence, and the reason for the odd distribution of the genes that allow it, you first need to think about cows. And not just about the animals themselves, but about the relationship between humans and cattle or other milk-producing hoofed animals—a relationship that extends back at least 7,000 years.

Cattle were originally domesticated for the usefulness of their meat and hides, not their milk, and some cattle-keeping humans still make little or no use of dairy products in their diets, relying on the animals for meat and hides. If you want to obtain milk from cows for human consumption, you have to take the calves away from their mothers while the mothers are still producing milk, and then selectively breed the females that are best able to keep up that production, eventually creating cattle that differ from their ancestors in the genes that control lactation.

To even think of making use of cow's milk, though, you have to have cows to begin with. And not all early peoples raised cattle. So what gave people the idea to raise cattle in the first place? Or, to put it another way, as Gabrielle Bloom and Paul Sherman of Cornell University asked, what kinds of environments make it too difficult to keep cattle or other ungulates year-round?[7]

Bloom and Sherman figured that in extremely hot or cold climates, or places where little food for the herds was found year-round, cattle would be too difficult to keep. More important, the prevalence of animal diseases such as anthrax and rinderpest in certain parts of the world can make it virtually impossible to successfully rear cattle and keep them healthy. Bloom and Sherman examined the relationship between where we see ancestral lactase persistence in the world and the geographic distribution of nine of these diseases, as well as the climate in which people with lactase persistence originated.

As they had predicted, people from parts of the world where the diseases had been prevalent were far less likely to exhibit lactase persistence, as were groups from extreme climate regimes, such as deserts or tropical rain forests. A few interesting anomalies emerged from this analysis: some groups of people live in areas that should be inhospitable to cattle, such as near-equatorial Africa or the Middle East, but nonetheless keep dairy herds and have a reasonably high rate of lactase persistence. Bloom and Sherman speculated that these people were able to overcome the barrier posed by the diseases by being nomadic, moving themselves and their cows around to avoid infection.

The cattle of today possess genes that are very different from those of their ancestors. Some of the change is a simple directional one; most modern domesticated dairy cattle produce far more milk over a much longer period, for example, than do either modern beef cattle or the forebears of either type. If you want more milk, you encourage early weaning; cows reared for meat are weaned late because the calves grow larger that way. Careful analysis of the teeth from cattle skulls dating back to the Neolithic reveals that the calves in such early herds were indeed taken from their mothers at a relatively young age, supporting the notion that cows were first domesticated for milk. In addition, where cattle are commonly kept, as in north-central Europe, the genes for different components of milk, such as the specific proteins, are quite variable. According to a research team led by Albano Beja-Pereira of France, this diversity of genetic types reflects the selective breeding of cows by early pastoralists, rather than new mutations arising in the different populations.[8]

A chicken-or-egg question, without chickens or eggs

The earliest remains of domesticated cattle date back about 8,000–9,000 years. Initially, before the controlled breeding mentioned in the previous section, and even now in some parts of Africa, the animals were used not as a source of fresh milk but for pulling plows or as sources of meat or blood. Fermented milk in the form of cheese or yogurt was sometimes consumed, but these dairy products usually have little lactose and hence cause fewer digestive problems than fresh milk does.

To understand the evolution of lactase persistence, it's important to know which came first: milk drinking or the change in the lactase gene. In other words, did early humans somehow evolve the ability to tolerate lactose, via the random changes in genes that occur all the time, and then start to use dairy and fine-tune their domestication of cattle; or did the gene for lactase persistence evolve because of the evolutionary advantage of dairy consumption? Finding the answer has required some of the most sophisticated genetics, and archaeology, of our time.

When the relative proportion of a gene in a population changes through chance, the process is called genetic drift. Drift happens in most if not all populations, but it is most common in small groups, simply because a change that is neutral with respect to evolution—providing its bearer with neither benefit nor cost—is more likely to become fixed in a population if there are not a lot of other options.

The concept of genetic drift is relevant to our understanding of lactase persistence because it is a kind of default hypothesis: instead of selection producing the change in gene frequencies, the revised proportion of milk digesters could have arisen by chance alone. Many forms of many genes come and go, and it is certainly within the realm of possibility that lactase persistence genes arose in a few human populations by chance—the actual chemical alterations required are not that complicated. The genes would then have become established in the population slowly, with nearby genes on the same chromosome as the lactase persistence genes changing independently of the ones conferring lactase persistence. In this scenario, one wouldn't expect to see big blocks of the same genes continuing to be associated with the lactase persistence genes.

Alternatively, if the gene rose in frequency not by chance, but because of selection favoring individuals who could digest milk, a different genetic pattern would be expected. In this case the genes surrounding the lactase persistence gene should be relatively more homogeneous than would be expected by chance, because strong selection would be carrying them along with the lactase persistence gene.

To picture this situation more clearly, imagine that the different forms of the genes are beads on a string, and then further picture the beads being able to slide on and off, with the probability of sliding increasing along with the amount of time that the beads stay together. If a string with the bead representing the lactase persistence gene keeps being plucked from the rest, it carries away, willy-nilly, the genes located next to it. The lactase persistence bead is propagated because it is advantageous, and the beads alongside are simply "hitchhikers," to use the genetic terminology.

Comparing these predictions—similarity of the blocks of genes near the lactase persistence gene, versus random assortment—requires fairly complicated statistical analysis, but with the ability to determine genetic sequences at a fine scale, it was possible to perform the critical test during the first few years of the twenty-first century. The answer? Selection. The beads—genes—associated with lactase persistence were much more similar than you would expect under a leisurely drift hypothesis. People able to drink milk without gastrointestinal disturbance passed on their genes at a higher rate than did the lactose-intolerant, and the gene for lactase persistence spread quickly in Europe.

It may seem implausible that such a modest ability would produce such a large change in an entire population, but a gene doesn't have to raise the reproductive success of its bearer all that much to become established. Anthropologists Rob Boyd and Joan Silk calculated that as little as a 3 percent increase in the reproductive fitness of those with lactase persistence would result in the widespread distribution of such a gene after only 300–350 generations.[9] That's about 7,000 years—a blink of the evolutionary eye. Other calculations have estimated that the forms of the gene allowing milk consumption are anywhere from about 2,200 to 20,000 years old—again, a shockingly brief interval in our history. But it seems to have been enough for at least some of us to take a step away from our early human ancestors.

What this means is that our own genome has evolved because of our cultural practices. Tolerating milk led us to keep more dairy cattle, which in turn continued to favor the genes for lactase persistence. This kind of coevolution, while not unknown before, is a beautiful example of what anthropologist Pascale Gerbault classifies as "niche construction."[10] All organisms inhabit what ecologists call a niche, a world defined by the requirements of the species; frogs need water, flies to eat, and weeds to hide in, while mosquitoes require hosts with blood and a refuge from swatters. The human niche is similarly constrained, and one of its proscriptions used to be milk. But once the early pastoralists evolved lactase persistence, we could shape our own destiny, in at least that one modest attribute. As anthropologist Alan Rogers put it, "We live in a radically changed environment, that we ourselves created."[11]

Calcium, food, and water

What makes drinking milk so beneficial? Why did selection favor those few with the ability to digest dairy after weaning? The most obvious reason is that dairy provides a supplementary source of nutrition, something that may be scarce for pastoralists. But scientists have suggested at least two other possibilities.

First, according to the calcium assimilation hypothesis, lactose tolerance is advantageous at high latitudes, where sunlight can be scarce and hence vitamin D levels low, because it allows more efficient uptake of calcium, much the way the vitamin itself does. Milk drinkers would thus be more likely to avoid the debilitating bone disease of rickets.

Alternatively, perhaps alongside either supplemental nutrition or calcium assimilation or both, is the notion that milk, above all, is a source of uncontaminated fluid, something that can be in short supply in the deserts of northern Africa. Compounding the danger of dehydration that the scarcity of water poses, one of the effects of lactose intolerance is diarrhea, which dehydrates the body even more. Members of the Beja, a nomadic people who herd camels and goats in the arid lands between the Nile and the Red Sea, drink about 3 liters of fresh milk each day during the lengthy dry season. If they could not digest lactase, the lives of these pastoralists would be difficult, if not impossible.

Gerbault and colleagues examined the distribution of lactase persistence across Europe and the Middle East. How, they asked, does milk drinking correlate with the amount of dairy herding by a given group of people, the archaeological evidence of the start of cattle domestication, and the changes that have occurred in other variable genes besides the ones for lactase persistence? The scientists conducted computer simulations in which they entered a variety of starting conditions for all of these variables and then asked whether one or more of the hypotheses for the advantage of milk drinking—better calcium absorption or the coevolution of people and cattle—explained the patterns we now see. It was difficult to separate the ideas, since both are compatible with the northern expansion of milk drinking in prehistory, but Gerbault's team concluded that the calcium hypothesis was a likely force in European, though not Middle Eastern or African, lactase persistence evolution.[12] To test the idea more thoroughly, genetic samples from people in other parts of the world, including Asia, where lactase persistence is relatively rare, would be needed.

A final hypothesis about the adaptive significance of lactose tolerance—or more accurately, intolerance—was proposed in the late 1990s by B. Anderson and C. Vullo of the Division of Pediatrics at the Santa Anna Hospital in Italy. They noted that malaria is a common disease in places where people are less likely to have lactase persistence. What's more, people who do not consume milk can suffer from low riboflavin levels, particularly if they are otherwise poorly nourished. The parasite that causes malaria doesn't grow as quickly in cells that lack flavin, so Anderson and Vullo speculated that people without lactase would be protected from the disease.[13] In this view, the trait that evolved in response to selection was the inability to digest milk, not the persistence of lactase. This seems an unlikely scenario, however, given that all other mammals lose the ability to digest lactose after weaning, making lactose intolerance a more likely ancestral state. Further research also revealed no connection between malaria and the genes for lactase persistence.

Africa, the milky continent

Africa is a funny place when it comes to milk. Lactose tolerance in northern Europe arose well after early humans had left Africa. If we accept the idea that selection on humans in Europe caused

them to evolve a high degree of lactase persistence, then what are some groups of people in Africa, like the Beni-Amir pastoralists in Sudan, doing with a 64 percent frequency of lactase persistence? Isn't it just too much of a coincidence to assume that such widely separated people evolved the same mutation at more or less the same time?

Geneticist Sarah Tishkoff of the University of Pennsylvania discovered the answer to this question by driving along the rutted—sometimes nonexistent—roads of East Africa, asking people from forty-three ethnic groups to participate in a study.[14] She and her colleagues asked 470 volunteers to drink a solution of powdered lactose dissolved in water. The scientists then took blood samples at timed intervals to collect information about lactose digestion and a sample of the individual's DNA at the same time. This test for lactose tolerance is not as accurate as the ones given in a Western medical facility, but it was far more feasible to administer in the field.

Tishkoff and her coworkers looked at their subjects' DNA for genetic variations near the lactase gene itself, where the lactase persistence alterations had previously been discovered. They found a consistent pattern of a few of these variants in people who could tolerate lactose consumption, but the genes that had become altered were different from the ones previously discovered in northern Europeans. In other words, Africans had evolved lactase persistence independently of the Europeans, with the same trait—being able to digest milk—arising from different genes. In both places, however, the people who can tolerate lactose are, with a few exceptions, the ones whose ancestors kept cattle and other milk-yielding animals.

The African version of lactase persistence also arose more recently than the European version, given that people did not start keeping herd animals in southern Kenya and northern Tanzania until just over 3,000 years ago. Thus, lactose tolerance is one of the best examples not only of rapid evolution, but of convergent evolution, the independent evolution of a similar trait via different pathways. Other cases of convergent evolution include the wings of birds and bats, which have the same function but are anatomically quite distinct, and the sonar-like echolocation systems of some whales, bats, and shrews. The lactase example is more cryptic than these, since although no one would have suggested that wings arose in the common ancestor of birds and bats, the idea that humans evolved lactose tolerance only once seems on the surface to be more plausible than the reality of multiple occurrences.

Interestingly, about half of the Hadza people of Tanzania were found to have the lactase persistence gene—a hefty proportion, given that they are hunter-gatherers, not herders. Why did the Hadza evolve a trait they don't use? Tishkoff and coworkers speculate that the gene might be useful in a different context. The same enzyme that enables the splitting of the lactose molecule is also used to break down phlorizin, a bitter compound in some of the native plants of Tanzania. Could the lactase persistence gene also help with digestion of other substances? No one knows for sure, but the idea certainly bears further investigation.

Microbes, milk, and what's to come

Despite the strong evidence for recent evolution of lactase persistence in humans via natural selection, a number of questions remain. How exactly does the mutation in a gene associated with the lactase molecule manage to keep the ability to break up lactose in adults? And why does lactose tolerance stop at different times for different people? Finns generally have high levels of lactase persistence, but some of them lose the ability to digest lactose as teenagers, rather than either retaining it throughout life or losing it as small children. Addressing this problem means understanding how genes regulate each other at different times during the life span—a fundamental question in human biology.

At a more practical level, what does the evolution of lactase persistence mean for modern people who are concerned about dairy consumption? It certainly puts to rest the notion that because dairy "is not paleo," it is not an appropriate part of the human diet. One's ability to digest milk simply depends on one's genes, and those genes have changed, at least in those of us whose heritage is rooted in pastoralists. (Note, as I mentioned earlier, that milk allergy, which is an immune reaction to the proteins found in milk, is distinct from lactose intolerance; both are genetic, but they arise from completely different genes.) Of course, people choose not to consume many foods they are capable of digesting, but the story of lactase persistence is an object lesson in escape from paleofantasy.

The science, of course, continues. A different way of trying to understand the question of variability in lactose tolerance might lie in another anomalous African population. At least some Somali people consume plenty of fresh milk but lack the genes identified by Tishkoff and others that should allow them to do so—rather a reversal of the Hadza. Catherine Ingram and others at University College London suggest that gut flora in the Somali may break down the lactose, making it easier to digest, in much the same manner that milk products such as yogurt and cheese are made digestible when their lactose is broken down in fermentation. Many people who are lactose-intolerant have an easier time digesting these products than they do fresh milk.[25] It is tempting to speculate that a particular set of bacteria and other microbes were subject to selection among the Somali, which meant that they achieved the same end as the Europeans and other Africans with the lactase persistence gene, but through yet another means.

The analysis of our internal microbiome, the diverse array of microscopic organisms living on and inside of us, is one of the most exciting emerging sciences. It may help us understand how the Somali, the Hadza, and the Finns evolved convergent digestive abilities, despite their wide geographic separation. Consumption of dairy exquisitely illustrates the ongoing nature of evolution, in humans as in other living things. Our ancestors had different diets, and almost certainly different gut flora, than we have. We continue to evolve with our internal menagerie of microorganisms just as we did with our cattle, and they with us.

5

The Perfect Paleofantasy Diet

MEAT, GRAINS, AND COOKING

In late 2010, headlines and blogs were full of a new discovery about Paleolithic humans. Every major news outlet and many of the more obscure ones covered the finding, with the usual interviews of the study's authors, comments by experts not involved in the research, and speculations about its implications for modern urban life.

The discovery was not a new fossil, or a redrawing of the map of human migration out of Africa. It was not an analysis of ancient DNA, or even of the human form at all. Anna Revedin of the Italian Institute of Prehistory and Early History in Florence, along with her Italian and Czech colleagues, detected bits of starch grains from plants, including cattail-like root particles, on the grinding stones from 30,000-year-old archaeological sites in Italy, Russia, and the Czech Republic. The scientists concluded that our ancestors were making flour and mixing the ground-up plants with water to make what one member of the team, Laura Longo, called "a kind of pita," cooked on a stone heated in the fire.[1]

Several related recent discoveries went more directly to the way hominins not only prepared but consumed starch: the teeth. A team of researchers led by anthropologist Amanda Henry analyzed the plaque clinging to teeth of Neandertals, which seem to have survived, in those preflossing days, with the remnants of meals intact.[2] The plaque is easily distinguished from dirt or other contaminants on the teeth, and Henry and her colleagues found clear evidence of grass seeds, date palms, and a few other plants. What's more, the outer parts of the starch grains were gelatinized—a transformation that occurs only via heating, which means that Neandertals cooked their food. Interestingly, the various plants found in the ancient teeth are ripe at different times of year, suggesting further that the Neandertals may have returned to various sites to harvest the grains. Another study by Henry and colleagues found similar plant remains in the 2-million-year-old teeth of *Australopithecus sediba* from South Africa.[3] The two individuals examined also had remains of bark and wood in their teeth, as well as a wide variety of leaves and other softer plant material. This diet bears a strong resemblance to that of most living primates, but not to the supposedly carnivorous human ancestors cited by the paleo enthusiasts.

So early humans ate crackers. What's the big deal? Modern versions of cattails and the other plants found in the remains associated with the grinding tools, such as bur reed, are known to be nutritious; archaeology blogger Kris Hirst noted that a single hectare of cattails produces 8 tons of flour.[4] The ground roots could be stored and transported, making people less dependent on the seasonal availability of game animals. Why wouldn't we expect our ancestors to have taken advantage of this useful resource?

The answer is that a reliance on starch in the diet calls into question the various forms of the so-called paleo diet, which, as I mentioned earlier, uses our ancestors as models for the way we should be eating. If people are vociferous in their opinions about milk, they are positively fervent in their feelings about grains and other carbohydrates as suitable components of the diet. "Bread" and "pasta" seem to be fighting words for many of the proponents of a diet more like that of early humans. From the *New York Times Well*

blog, for example, comes this quote: "Cereal grains like wheat, oats, barley, rye, maize and rice we started to consume between only 5,000 and 10,000 years ago and we are not used to it. Genetically we are still the hunter-gatherers from 190,000 years ago, adapted to meats, fruits and vegetables."[5] Eschewing grains often seems to be accompanied by an enthusiasm for carnivory, as this comment from Cavemanforum.com illustrates: "I personally can never get enough of pork belly (bacon without the crap). Yesterday, I had it with breakfast, lunch and dinner! At dinnertime, I had a pound of salmon steak, but I decided to fry up some pork belly afterwards. It's a good feeling."[6]

The first formalized suggestion that we should be relying on meat and modeling ourselves, at least foodwise, after our cave-dwelling ancestors came from *The Stone Age Diet*, a 1975 book by gastroenterologist Walter Voegtlin. Like its more recent successors, including *The Paleo Diet*,[7] *We Want to Live*,[8] and *The Paleo Solution: The Original Human Diet*,[9] *The Stone Age Diet* bemoans the modern Western diet of processed food high in starches. Voegtlin disapprovingly describes the average North American dinner of the time, in which "The average meat serving is modest and is often replaced with baked beans, macaroni and cheese, soy bean meat substitutes, or peanut butter. An array of vegetables is dwarfed by a mountain of mashed potatoes and gravy or a giant baked potato. Most families have bread or rolls with butter at dinner. Dessert is about the same as lunch [pie, cake, pudding, ice cream], only more of it."[10]

This way of eating, according to the supporters of various forms of the paleo diet, is responsible for our current obesity crisis, as well as the various "diseases of civilization," including type 2 diabetes, hypertension, and atherosclerosis. The problem, they claim, is that humans have not adapted to be able to safely consume grains, agriculture having arisen a mere 10,000 years ago, and hence reliance on carbohydrates takes us on an unhealthy and dangerously untrodden path from the diet we evolved to eat, which is meat based. The diets differ in their details, with various amounts and types of vegetables permitted, but they share an emphasis on meat and strictures against virtually all sweets and products using flour. A sample breakfast might include fruit and pork chops with herbal tea; snacks might consist of dried fish or meat and walnuts.

Voegtlin is dismissive of vegetarians, advocating a virtually completely carnivorous diet based on his (inaccurate, as I will explain) view of our evolutionary history. He declaims, "Did anybody ever tell you that your ancestors were exclusively flesh-eaters for at least two and possibly twenty *million* years? Were you aware that ancestral man first departed slightly from a strictly carnivorous diet a mere ten *thousand* years ago?"[11]

Voegtlin also warns against misapplying the evolutionary principles he promotes, with a story that one only hopes is apocryphal:

> The puerile syllogism that 1) man descended from apes; 2) apes eat coconuts; therefore 3) man should eat coconuts, impelled German August Engelhart [*sic*] to gather about him a group of disciples dedicated to eating nothing but coconuts. The community migrated to and became established on a South Pacific atoll. A fanatical disciplinarian, Engelhart decreed imprisonment and torture for those deviating in the slightest from the coconut diet. When the atoll was captured by the British during World War I only one survivor of the company was found—Engelhart himself—his legs swollen from starvation and his body a mass of putrid ulcers. He died shortly after being taken from the atoll with its abundant fish and shellfish population, which could have saved all the "cocovores" from protein malnutrition and death.[12]

Needless to say, current versions of the paleo diet do not assume that vegetarians are sticking to one food, coconuts or not. The fans of paleo also acknowledge that they are not necessarily emulating

ancestral diets in every respect, but using them as a jumping-off point. They still, however, eschew plant-based diets. The paleo lifestyle has been embraced by many people, with a number of informal online discussion groups arising in which practitioners share advice and ask questions. Cookbooks with titles like *Paleo Comfort Foods: Homestyle Cooking in a Gluten-Free Kitchen* and *The Paleo Diet for Athletes: A Nutritional Formula for Peak Athletic Performance* cater to specialized applications of the paleo diet.

The level of dietary and other detail is astonishing. Depending on where you look, people are advised to use coconut oil instead of olive oil, olive oil instead of coconut oil, or butter instead of either; to restrict nuts, or to eat macadamias instead of almonds; not to worry about eating nearly 6 pounds of ground beef in a day, but to be concerned about the high sugar content of watermelon; and to go to sleep when it is dark and wake when it is light, avoiding the use of alarm clocks. (Application of the latter recommendation to those people living in Scandinavia in the summertime is not addressed.) One practitioner consulted with a paleo discussion board because of a concern that eating more carbs was making his/her nose rounder ("when i stick to meat fat and veggies, it is pointier . . ."[13]). Others extend the back-to-the-cave movement to clothing, wondering which type of natural fibers—wool, silk, linen, or cotton—might be the most appropriate to wear (synthetics, of course, are out), calling to mind an interesting image of cave-based silkworm farms. Also, I can't be completely sure, but apparently some followers are eating horse fat. Is this really the solution to our health problems?

Amber fields of . . . game?

At a recent conference I attended,[14] Loren Cordain, author of *The Paleo Diet* and a well-known proponent of eating fewer refined grains as the key to health, gave a presentation to a small group of scientists interested in evolution and medicine. He outlined in persuasive detail the digestive and other health consequences of eating certain foods for people who have an alteration in a particular immune system gene. Potential offenders ranged from green tomatoes and root beer (not too much of a problem to give up) to bread, rice, and potatoes (ouch). Many of us can eat these foods with impunity, but to those unlucky enough to bear the gene variant, the foods can eventually cause something called "leaky gut," which you don't have to know anything about to know is something you don't want.

I was greatly intrigued by this information (and am cautiously optimistic that my gut is impervious, at least for the time being), but one thing puzzled me. Why, I asked Cordain, has this inability to properly digest all these common foods persisted? Surely it should have been selected out of the population.

He was taken aback. The answer was obvious, he responded. The sensitivity had been occurring only since the advent of agriculture, so humans haven't had an opportunity to adapt yet. I frowned. "Plenty of time," I said.

"But it's only been ten thousand years," he said.

"Plenty of time," I repeated. Now it was his turn to frown. We never resolved our disagreement, but it points to a question that is at the crux of this book. Is the diet envisioned by Cordain and other paleo proponents really "the one and only diet that ideally fits our genetic makeup,"[15] as his book would have it? Is it true, as he claims, that "just 500 generations ago—and for 2.5 million years before that—every human on Earth ate this way"?[16] We know that the lactase gene, for example, evolved quickly, allowing humans who could not have consumed dairy products without discomfort to do so if they inherited the gene. What about the rest of our digestion-related genes?

I want to make it clear that I am not discussing the relative health merits of the paleo versus Atkins versus Mediterranean diets, or

any other particular way of eating. I am also not concerned with the details of exactly how much animal protein in the diet is necessary to constitute a real paleo diet, or which micronutrients would have been present in which quantities of food in the period before agriculture. I also realize that not all paleo dieters are doing exactly the same thing, and that not all are really attempting to replicate ancient meals.

What's more, although I confess to a certain bemused fascination with the minutiae of, for example, how large a yam one can consume and still have the overall diet be considered paleo, I realize that virtually all diets—vegan, vegetarian, organic, and so on—have their fringe adherents, some of whom can become quite vehement. Many paleo eaters complain about being chided by virtuous vegetarians; one commenter on a blog who has not "knowingly consumed grain products for about 10 years, as well as processed sugary things" is "often lectured by people how humans can't survive without grains and must eat them (usually they are slightly overweight, puffy people who complain of various ailments)."[17] And certainly, eating mainly lean meat and few or no processed foods may well be healthy for at least some people, particularly when contrasted to a diet of Cheetos and Coca-Cola. The question is whether the various forms of the paleo diet really do replicate what our ancestors ate, and further, whether that should serve as a guide for us in the twenty-first century.

Nevertheless, the studies of the quality of paleo diets are at best mixed in their evaluations. In 2011, *U.S. News & World Report* had twenty-two experts, including physicians and professors of food science and nutrition at universities and medical schools, rank a variety of popular and relatively unknown diet plans, including various low-fat and low-carb options, as well as the paleo diet.[18] Then the experts "rated each diet in seven categories: how easy it is to follow [1], its ability to produce short-term [2] and long-term [3] weight loss, its nutritional completeness [4], its safety [5], and its potential for preventing and managing diabetes [6] and heart disease [7]. We also asked the panelists to let us know about aspects of each diet they particularly liked or disliked and to weigh in with tidbits of advice that someone considering a particular diet should know."[19]

The magazine defined the paleo diet as "the way we ate when we were hunting and gathering: animal protein and plants . . . if the cavemen didn't eat it, you shouldn't either. So long to refined sugar, dairy, legumes, and grains (this is pre-agricultural revolution); hello to meat, fish, poultry, fruits, and veggies."[20]

The results? The paleo diet came in dead last, at rank 20. "Experts took issue with the diet on every measure. Regardless of the goal—weight loss, heart health, or finding a diet that's easy to follow—most experts concluded that it would be better for dieters to look elsewhere. 'A true Paleo diet might be a great option: very lean, pure meats, lots of wild plants,' said one expert—quickly adding, however, that duplicating such a regimen in modern times would be difficult."[21] Modern foods, as I detail later in this chapter, are often much higher in fat and sugar than their wild counterparts—a difficulty acknowledged by at least some of the paleo enthusiasts.

A few studies have attempted to examine the effects of switching to a paleo diet on various health measures, including weight, of groups of subjects. Unfortunately, as with all diets, doing a carefully controlled examination of the paleo diet is difficult. One such attempt took twenty healthy volunteers and measured variables such as body weight, waist circumference, cholesterol levels, and blood glucose before and after the three weeks of the study.[22] Only fourteen of the subjects managed to complete the entire three weeks, and they lost an average of 5 pounds, with a 0.2 decrease in waist circumference (they were not overweight to begin with). Blood calcium levels fell by more than 50 percent—not surprising, since the subjects were not allowed to eat dairy and received no special instructions on how to obtain specific nutrients from the foods they were allowed.

The National Health Service of the United Kingdom analyzed the study, which was widely reported as confirming the health benefits of paleo eating, and was not impressed.[23] It pointed to the absence of a control group—a comparison group eating in a different way, to which the participants could be compared—making it difficult to interpret the findings. The NHS also noted that a dropout rate of 30 percent suggested that the diet might be difficult to follow for most people, which means that regardless of its virtues, a paleo diet might not be a panacea for the diseases of civilization.

The hunter-gatherer table—or, mole rats and starch

Cartoon images of early hunters living exclusively off the flesh of mammoths notwithstanding, Voegtlin's bold declaration that our ancestors consumed exclusively meat turns out to be untrue. Studies of fossil hominins suggest that their sturdy premolar teeth may have been used either to open seeds or to chew starchy underground tubers and bulbs. One rather unusual clue about ancestral diets comes not from fossil humans themselves, but from the fossils of mole rats, bullet-shaped rodents that live in underground colonies with elaborate tunnel systems and rely on the enlarged potato-like roots of wild plants for both food and water.

A mole rat away from tubers is a sad and hungry mole rat, so when groups of mole rat fossils are discovered, it means that these underground food sources must have been nearby. And indeed, mole rat fossils occur at the same sites as hominin remains much more often than would be expected by chance, suggesting that early humans also used these roots and other starchy foods. They may have used them mostly as "fallback foods" in times of scarcity, but even so, such foods would have allowed early humans to survive periods when hunting was simply not an option.

Finding out that early humans ate starchy foods is one piece of the puzzle. The other source of information about what our forebears' diet might have been like is the diet of people now living the way we think our ancestors did, as foragers and hunters. As I mentioned in Chapter 2, there are many caveats to using modern hunter-gatherers as surrogates for early humans, but keeping those in mind, we can learn, for example, that the different cultures using foods they catch and glean eat a huge variety of different things, both plant and animal. It should come as no surprise that this variety is tightly linked to the range of climates and environments in which humans live; more northern peoples eat more meat and less plant material, while coastal cultures eat fish.

Anthropologist Frank Marlowe painstakingly examined the eating patterns and environments of 478 groups of humans across the planet, from the southern tip of South America to northern Alaska, and from eastern Australia to Africa.[24] He points out that whether you rely primarily on plant as opposed to animal foods depends on where in the world you live; Old World foragers get more of their diet from gathering and less from hunting and fishing, with the converse true for those in the New World. Even among the latter, however, nearly a third of the diet comes from plants, putting to rest the notion of our carnivorous ancestors. Climate matters as well, with those living in warmer parts of the world closer to the equator obtaining a larger fraction of their food via gathering, as would be expected, given the difficulty of acquiring fruits or other plant products in a harsh climate.

One of the most interesting distinctions in Marlowe's survey is between cultures that use bows and arrows for hunting and those that do not. Bows enable the killing of animals at a much greater distance than do spears, as well as the bringing down of larger game. As a result, it is possible to increase meat consumption, which Marlowe speculates could have spurred the growth in the human population after bows had become established in early

societies. He further notes that if we are to use modern hunter-gatherers as models for the earliest of humans, we should probably stick to those groups that lack the bow, because they are the most similar to our ancestors, which leaves us with indigenous Australians and Tasmanians. Bow use is a deceptively simple advance with the potential to substantially alter the food base of a society, and it is yet another example of a subtle way in which preagricultural humans varied from a uniform hunter-gatherer model.

Another implication of the importance that Marlowe attaches to bow hunting is that, rather than starting out as exclusively carnivorous and then adding starches and other plant material to the diet, ancient humans would have been able to increase the proportion of meat only after newer technology had come about, a mere 30,000 years ago. Other anthropologists concur that the amount of meat in the human diet grew as we diverged from our other primate ancestors. All of this means that, first, contrary to the claims of many paleo-diet proponents, the earliest humans did not have an exclusively meat-based diet that we are best adapted to eat; and second, our ancestors' diets clearly changed dramatically and repeatedly over the last tens, not to mention hundreds, of thousands of years, even before the advent of agriculture.

What people eat is also inextricably entwined with how people spend their time, and in particular with how men and women might differ in this regard. I discuss paleofantasy gender roles in Chapter 7, but it is worth mentioning that the relative amount of the food budget supplied by men versus women, related to the reliance on hunting versus gathering, is another attribute that varies across cultures. Also tied to the appearance of bow hunting was the ability of men to provide a larger proportion of a family's caloric intake, since they were killing larger animals. Marlowe speculates that before this technological development, men might have been contributing different non-meat-based foods, such as honey, with women providing the bulk of the food eaten by the group, as was the case for the indigenous Australians in his sample.

Katherine Milton is a primatologist and anthropologist at UC Berkeley who has studied and written extensively about the diets of modern apes and monkeys, as well as those of hunter-gatherers and ancient humans. She points out that "it is difficult to comment on 'the best diet' for modern humans because there have been and are so many different yet successful diets in our species."[25] Furthermore, "Because some hunter-gatherer societies obtained most of their dietary energy from wild animal fat and protein does not imply that this is the ideal diet for modern humans, nor does it imply that modern humans have genetic adaptations to such diets."[26] Milton also takes issue with the attempt by paleo-diet experts to calculate the ratios of nutrients such as protein or saturated fat in hunter-gatherer diets so that these can be emulated by followers of the paleo way of life, again citing the vast range of diets eaten by modern foragers and the lack of detailed information on foods eaten by early humans.

Even if we did know more about what our ancestors really ate, Milton argues that it wouldn't necessarily help, because those ancestors do not seem to have been particularly specially adapted to their foods, or as she says, "regardless of what Paleolithic hunter-gatherer societies were eating, there is little evidence to suggest that human nutritional requirements or human digestive physiology were significantly affected by such diets at *any* point in human evolution."[27] The notion that humans got to a point in evolutionary history when their bodies were somehow in sync with the environment, and that sometime later we went astray from those roots—whether because of the advent of agriculture, the invention of the bow and arrow, or the availability of the hamburger—reflects a misunderstanding of evolution. What we are able to eat and thrive on depends on our more than 30 million years of history as primates, not on a single arbitrarily more recent moment in time.

Milton hastens to point out, and I wholeheartedly concur, that this does not mean that many of the diseases of civilization are unrelated to diet, or that we should go further back and emulate the diets of gorillas or other modern apes rather than hunter-gatherers. If the proponents of paleo diets were correct, however, those hunter-gatherers with higher levels of protein in their diets should be less likely to suffer from modern maladies like obesity and hypertension than do cultures consuming more plants and starches, but no evidence exists to support such a claim. Such diseases are indeed absent in most foraging societies, but they are more uniformly absent than would be expected if a high meat intake were the preventive. The biggest problem with many Western diets seems to be their energy density—the vast number of calories contained in a Big Mac as opposed to an equal volume of wild fruits or game. The concentration of calories makes it far too easy to overconsume, even when it feels as if the amount of food eaten is not particularly large.

The relative proportion of carbohydrates in the diet does affect one aspect of our health: our teeth. But here the problem arose not with a switch to agriculture, but much later, when the Industrial Revolution led to increased consumption of refined sugars and processed foods. A 2012 conference at the National Evolutionary Synthesis Center in North Carolina examined the dental health of modern humans compared with that of either modern peoples eating more traditional diets, such as the Maya of Mexico, or our fossilized ancestors. People in industrialized societies not only have far more cavities than either of the other two groups—Australian aboriginals from the 1940s were described as having "beautiful teeth"—but their jaws are shaped differently, with malocclusion and overcrowding of the teeth.[28] Ancient people and those consuming more fibrous foods simply chew more, which changes the development of the jawbones and associated musculature.

The scientists who studied early dental health are quick to caution against a quick fix of a paleo diet for those seeking to avoid the dentist and orthodontist; Peter Ungar from the University of Arkansas echoes anthropologists in saying, "There was not a single oral environment to which our teeth and jaws evolved—there is no single caveman diet. Still, we need to acknowledge that our ancestors did not have their teeth bathed in milkshake."[29]

One potato, new potato

Even if we wanted to eat a more paleo-like diet, could we? Virtually all of the foods available to those of us not living foraging lifestyles are vastly different from the forms that our Paleolithic ancestors would have eaten. I am not talking about ice cream or Pop-Tarts, or even flour, but about the unprepared basics: meats, fruits, and vegetables.

Many of the paleo-diet fans promote eating wild game, or at least very lean cuts of meat—a reasonable recommendation, given the differences in the fat content of domesticated animals compared to their wild counterparts. For example, according to the Department of Animal Science at Texas A&M University, a 4-ounce serving of white-tailed deer meat has 2.2 grams of fat, while a similar-sized portion of extra-lean ground beef has 18.5 grams of fat.[30] Game birds such as pheasant or quail have about half the calories of commercially available beef and pork. Domesticated animals that are used for food have been selectively bred, of course, to grow quickly, resist disease, and be amenable to living in much larger groups than their wild ancestors would have tolerated—all qualities that may or may not be compatible with a goal of maximal human nutrition. This is not to suggest that modern meat is unhealthy per se, but merely that eating like a caveman is going to involve more than skipping everything except the butcher counter at the supermarket.

The produce aisle has its problems too. Virtually all commonly eaten fruits and vegetables are also the result of much selective

breeding by generations of farmers, whether one is growing one's own or shopping at the supermarket, using heirloom varieties or not. The ancestral potato, for example, was a bitter, lumpy root a fraction of the size of the average Idaho baker. The wild progenitor of apples, recently traced to Kazakhstan in Central Asia, was described by Michael Pollan as "a mushy Brazil nut sheathed in leather" that would "veer off into a bitterness so profound that it makes the stomach rise even in recollection."[31] What we now know as corn started out about 9,000 years ago as a Mexican grass called teosinte, with a shape and size more reminiscent of a stalk of rice than of the fat yellow kernels on a cob. Several researchers who followed wild monkeys or apes and attempted to eat the same fruits and other plants that those animals eat reported similar off-putting results.

Of course, the news isn't all bad. Milton examined eighteen species of wild Panamanian fruits eaten by several monkeys, and found that they averaged 6.5 percent protein, compared with just over 5 percent protein for cultivated fruits from the grocery store.[32] A similar analysis of fruits eaten by chimpanzees in Africa showed a protein content of over 10 percent.[33] Wild fruits also are more apt to contain worms and other insect infestations, probably adding negligibly to the protein content but, according to Milton, potentially increasing vitamins, amino acids, and other micronutrients not usually available in the fruit itself. And some fruits are quite large, sweet, and juicy even in an unmodified form, particularly tropical varieties like relatives of the soursop.

The point is that most modern foods, whether processed or not, are a far cry from their wild ancestors, having been enormously modified by people seeking a more calorie-rich, more easily transportable, or simply tastier version of the original. Many of the paleo-diet enthusiasts realize this, and the discussion boards are full of debates on whether to therefore stick to less sweet fruits such as avocados (to which other posters respond by noting that early forms of avocado are basically a large pit surrounded by a thin layer of, well, avocado flesh, which doesn't have much substance to it). The reality is that we are not eating what our ancestors ate, perhaps because we do not want to, but also because we can't.

In addition to shunning grains and the foods made from them, paleo-diet followers are concerned about eating starchy vegetables and tubers, such as potatoes. Sweet potatoes seem marginally better than the rest, but differences of opinion abound. One blog contributor eschewed all forms of potatoes, concluding by saying, "To summarize, there's 3 problems with tubers: a) Poisonous substances; b) Carb load; c) Problems we are yet to discover."[34] Arguably, this list contains either two problems or an infinite number, depending on your interpretation of point (c), but the interesting issue from my perspective is the first: the existence of toxins in tubers and many other wild foods.

Potatoes are from the same plant family as deadly nightshade, and the leaves and fruits contain several poisonous compounds, including solanine, which can cause digestive illnesses and, in large amounts, coma and death. Eating the potato itself avoids these substances, and one would have to consume quite a bit of the leaves or other parts of the plant containing these poisons to suffer ill effects. Nevertheless, the possibility of getting sick from one's food source unless one knows exactly which part to eat raises an interesting question: How did people figure out that the ancestors of potatoes were edible to begin with? Some other plant foods, such as acorns, require substantial treatment before they become non-toxic; Native Americans leached the poisonous tannins from acorns with successive washes before grinding them into acorn meal.

How in the world did people figure out what to do to render such initially inedible, even dangerous, plant products into palatable food? One assumes that necessity was the mother of invention, but the details of discovery, and the missteps—perhaps deadly—along

the way, remain unknown. George Armelagos, an anthropologist at Emory University, suggests that distinctive cuisines developed as a way of restricting the potential for eating poisonous or otherwise unsafe foods in the environment.[35] That, too, however, underscores the flexibility of ancestral eating. We did not have a single diet, regardless of the relative compositions of fruits, nuts, tubers, and meat, throughout the period between the evolution of the genus *Homo* and the development of agriculture. Instead, people in different places ate different foods, modified them to differing degrees, and thrived on the variety.

The pot and the spit

Although the ability to digest the wide variety of carbohydrates available is more complicated than lactase persistence, involving more biochemical and physiological processes, in at least one respect humans have also evolved adaptations to eating starches, and relatively recently at that. Humans in different places have been eating different diets for thousands of years. The Japanese, for example, have been consuming starches in the form of rice for thousands of years, while people of the far north, such as the Yakut of Siberia, rely on hunting and fishing for sustenance.

A recent study by George Perry and colleagues asked the deceptively simple question of whether these two groups of people, and others like them, had evolved any adaptations to their different diets. As your mother may have told you, chewing food before swallowing it is important for proper digestion, in part because the enzyme amylase in saliva helps to break down starch. Salivary amylase also remains in the stomach and intestine after the food is swallowed, aiding the further digestion of starch by additional amylase present in the pancreas. Salivary digestion of starch, and therefore the presence of amylase, is crucial if an individual is suffering from diarrhea, since food is insufficiently digested in the intestine during such illnesses.

Perry and his coworkers looked for genetic differences in amylase genes from human populations with relatively low and high historical starch consumption: two African hunter-gatherer groups, an African pastoralist group, and the Yakut for the former; and European Americans, Hadza hunter-gatherers (who rely on starchy tubers) from Tanzania, and Japanese for the latter.[36] The researchers acknowledge that the diets are not mutually exclusive in their ingredients, but the two categories still show substantial differences.

The scientists examined not the structure of the amylase gene itself, but the number of copies of it in the genomes of the two sets of populations. Like many genes, the amylase gene is prone to duplication, with multiple copies existing in some individuals but not others. A person inherits the number of copies from his or her parents—in other words, the duplication does not occur during each individual's lifetime—but the likelihood that a duplication event will spread depends on whether or not it is advantageous. Gene duplication may have little or no effect, depending on what the gene does, but in the case of amylase, having more copies means that the individual is better able to digest starchy foods—an obvious advantage for people whose diet includes them. Perry predicted that the high-starch-consuming people would possess more copies of the amylase gene than the meat and fish eaters had. He was right; in the high-starch populations, 70 percent of the people had at least six copies of the amylase gene, but in the low-starch populations, that proportion dropped to just 37 percent.

Confirming the idea that the humans eating more starch evolved their higher number of copies of the amylase gene is the discovery that the levels of salivary amylase in chimpanzees are one-sixth to one-eighth what they are in humans. Chimpanzees eat a very

low-starch diet, and geneticists Etienne Patin and Lluís Quintana-Murci from the Pasteur Institute in Paris suggested that a low copy number would have been found in our common ancestor, as well as in early humans.[37] (A section of their paper is titled "Adjusting the Spit to the Pot," which I stole as the heading for this section.) Then natural selection would have favored individuals with more copies as the amount of starch in the diet increased, so that the early agriculturalists could take advantage of the new foods. Cereal crops such as barley or rice probably were not domesticated until people had evolved more efficient starch digestion.

Interestingly, although chimpanzees and their close relatives the bonobos do not produce significant amounts of amylase, the Old World monkeys called cercopiths, a group that includes macaques and mangabeys, do. Perry and his colleagues speculate that the monkeys might use the enzyme to help them digest starchy foods, such as unripe fruit, that they store in their cheek pouches—a habit that only this group of monkeys possesses.[38]

Although we cannot go back in time to test early humans for the presence of amylase gene copies, an opportunity might exist, at least in theory, to do the next best thing. Until very recently, a small group of people in the remote mountains of northern Thailand and western Laos, the Mlabri, lived a nomadic hunter-gatherer lifestyle. But their language and culture, as well as the similarity between their genes and those of related peoples in the region, suggest an intriguing history. Hiroki Oota and colleagues believe that the Mlabri used to be agricultural but "reverted," in their words, to foraging, perhaps because the founding group of people was simply too small to support planting and harvesting of crops.[39] Depending on how recently the shift occurred (the data suggest anywhere between 500 and 1,000 years ago), it is possible that the Mlabri have a higher-than-expected number of amylase gene copies—a holdover from their farming past and a departure from other hunter-gatherer groups.

Agriculture's bitter legacy

Which other human genes associated with diet may have changed since the development of agriculture? Lluís Quintana-Murci of the Pasteur Institute has also studied an enzyme called NAT2, which was first described because of its role in metabolizing drugs used in treating hypertension and tuberculosis, but which is also important in breaking down toxins from plants and cooked meat. The gene that codes for NAT2 comes in several forms, with one form more common among hunter-gatherers and the other more common in people whose ancestors were agriculturalists.

Quintana-Murci and his colleagues believe that the variation in NAT2 has to do with the availability of folate in the two types of populations.[40] Folate is the naturally occurring form of folic acid, a substance known to many people because of its role in preventing miscarriage and birth defects, particularly spina bifida. Pregnant women are often encouraged to take folic acid supplements to ensure that their diets have enough of the compound. Folate is found in leafy greens or liver, neither of which are likely to be eaten in large amounts by agricultural peoples relying on grains for much of the diet.

NAT2 is also used to break down folate in the body, which means that having a gene variant that increases the rate of folate processing is a disadvantage if folate supplies in the diet are low; it's like enlarging the holes of a sieve when the flow of water is decreasing. So it's possible that natural selection favored people with less active forms of NAT2 after agriculture arose. At the same time, if folate is plentiful, metabolizing it more effectively could have helped reduce birth defects and the loss of pregnancies in hunter-gatherers. Support for this idea was found by a French research team led by Audrey Sabbagh, who surveyed the NAT2 variants of over 14,000 people from 128 different populations with a variety of diets. As

expected if NAT2 is helpful when folate is abundant but harmful when it is scarce, foraging people were far more likely to possess the active form of the gene.[41]

Similar trade-offs between the advantages and disadvantages of genes associated with the diet are seen in the way we taste our foods. Humans have a remarkable sensitivity to bitterness—a useful ability, given the numerous bitter-tasting toxic compounds in wild plants—and several genes are responsible for the variation among people in their sensitivity to bitter flavors. Ordinarily, being more sensitive to bitterness is better, because it enables the taster to reject a potentially poisonous food source before eating too much of it. Among some people of central Africa, however, a gene variant that makes the bearer less able to taste bitterness is extremely common, despite the use of cassava, a starchy (and somewhat bitter-tasting) root, in that region. When some compounds in cassava are broken down in the gut, they release cyanide, which is obviously toxic in large quantities. If enough protein is present in the diet, however, people can tolerate small amounts of cyanide, so it is not automatically deadly. The less discerning gene variant may persist because it also renders those who carry it more resistant to malaria, which is endemic in the region. The distribution of the less sensitive variant mirrors that of the malaria parasite in Africa. Interestingly, some bitter-tasting plants in the region also have antimalarial activity, suggesting that humans with less sensitivity to the plants' taste may be more willing to ingest them.

Dietary signatures

Although the method of analyzing a gene here and an enzyme there has its appeal, many researchers are now taking a broader approach to the question of recent diet-induced changes in our genes. Modern genetic tools allow scientists to survey the whole genome—our entire collection of genes—at once, or at least to compare large chunks of it among different populations with different diets or ancestry. These techniques can uncover more subtle genetic changes than those affecting lactase persistence or amylase—changes that are caused by tiny alterations in many genes acting together, rather than by a single dramatic shift.

The basic idea is simple. Genes occur together on the chromosomes like houses on a street, with some neighbors closer than others. Like other organisms, humans have chromosomes in pairs, with alternate forms of a gene on each member of the pair. When sperm and eggs are produced, they each have only one member of the pair, so that when they join to make a baby, the child has the normal number of chromosomes. But before the chromosome pairs unzip, they swap some of the genes at locations across from each other; to continue with the house analogy, it is as if one of the even-numbered houses on one side of the street were exchanged for one of the odd-numbered houses on the opposite side. This genetic recombination is why children produced by the same parent differ from one another, even though they each get half their DNA from their mother and half from their father. Usually genes are swapped in big chunks, with several sequences of DNA linked together. The closer any single piece of DNA is to another, the more likely the two will be recombined together, so—returning to the house analogy—houses on the same city block tend to stay together for longer than do houses on adjoining blocks.

Suppose that a new gene allowing better digestion of grains arises in a population. Such a gene would confer an advantage to its bearer and hence is expected to spread quickly, as the children of the cereal lover, and then their children, pass on the gene. As they do so, however, these individuals also inherit the DNA that was located on either side of the gene, which is less likely to have been broken up in the process of recombination, simply because strong selection on the grain-digesting gene has taken its neighbors along with it.

What this means is that scientists can scan the genomes of people living in different parts of the world who have historically eaten different diets, or the genomes of humans and our close relatives the apes, and look for signs of suspiciously large chunks of DNA that seem to have been passed along intact, as you would expect only if selection favored a gene and then its neighbors were carried along with it in the haste of evolution. After these chunks are identified, it's possible to determine what the genes within the chunks can do: Are they associated with metabolizing protein? Do they detoxify plant compounds? Finding a large number of these changes means that our genes have changed relatively rapidly, in response to the new selection pressures caused by shifting diets.

Using these and similar techniques, Anna Di Rienzo at the University of Chicago and her colleagues found that humans show different genes associated with metabolizing food and accommodating the environment depending on where they live, or at least on where their ancestors came from.[42] Polar people's genes, for example, reflect an ability to deal with cold stress, and foragers appear to be adapted to a wider variety of foods than are the more specialized agricultural peoples. Liver enzymes associated with detoxifying the compounds found in roots and tubers are more prevalent in the nonpolar regions, where hunting is not the main source of food, as are genes associated with digesting cereals.

This branch of science, while attracting a great deal of attention, is still in its infancy; though researchers can identify and sequence stretches of DNA, assigning those sequences to a given function is not at all straightforward. And when many genes all contribute a small amount to a particular dietary ability, unlike the situation for lactase persistence or starch digestion, it is extremely challenging to chase them all down. Nonetheless, a strong body of evidence points to many changes in our genome since humans spread across the globe and developed agriculture, making it difficult at best to point to a single way of eating to which we were, and remain, best suited.

Sushi and dietary companions

The very newest discoveries about our dietary evolution may lie not in our own genes, but in those of the microbes we carry with us—in our guts, on our skin, and in the soil and air around us. When we digest food, we do not do it by ourselves, and I am not referring to having the family sit around the dinner table. We've all heard that some gut bacteria aid digestion, and perhaps that we can influence such bacteria by eating fermented foods like yogurt. But the real story is much more dramatic. The human cells of our bodies are outnumbered by microorganisms by a ratio of about ten of them to every single cell of ours. The microbes are part of our immune system and our sense organs, as well as our digestive tracts, and we could not survive without them. Pieces of their DNA lie intermingled with our own.

This microbial companionship might even have directed our dietary evolution. A recent study led by Jan-Hendrik Hehemann and his colleagues suggests a previously unconsidered mechanism for changing our genes under different dietary regimes.[43] The Japanese eat rather more seaweed than do other groups, averaging just over 14 grams per person each day. Seaweeds in turn harbor microorganisms of their own, including some that can help break down some of the carbohydrates in the seaweed. Unlike larger and more complex organisms, microbes from rather different groups can transfer genes to each other; the two types don't have sex exactly, but undergo a process called horizontal gene transfer. By this means, the genes from the seaweed microbes appear to have been transferred to the gut bacteria of people who tend to consume a lot of seaweed. The seaweed microbe genes thus were found in the intestinal flora of Japanese but not North Americans. It is clear that the Japanese did not get the genes simply by eating sushi, because

one of the Japanese study subjects was a still-nursing infant who was not consuming solid food at all.

Other hints that intestinal microbes could affect the ability to consume new foods come from the finding that some people who do not have the lactase persistence gene can digest milk products; it is possible that they acquire microbes that do the job for them. Such gene transfer, and the interaction between us and our invisible companions, poses an extraordinary new avenue for rapid adaptation to the environment. Microbiologist Jeffrey Gordon says, "The gut microbial community can be viewed as a metabolic organ—an organ within an organ . . . It's like bringing a set of utensils to a dinner party that the host does not have."[44] As our diets change, so does our internal menagerie, which in turn allows us to eat more and different kinds of foods. The caveman wouldn't just find our modern cuisine foreign; the microbes inside of us, were he able to see them, would be at least as strange.

I realize that most people, whether or not they find the idea of genes hopping between the seaweed's internal flora and our own of interest, really want to know what these findings about the recent evolution of our diets mean for what they eat. The answer is that no one, whether a low-carb enthusiast, a proponent of bacon fat, or a fan of organic food, can legitimately claim to have found the only "natural" diet for humans. We simply ate too many different foods in the past, and have adapted to too many new ones, to draw such a conclusion. If the genetic tools to characterize each individual's diet-related genes are developed, we might be able to examine the suitability of particular diets for certain people. But that day has not yet come.