"A new way of thinking about illness . . . a fascinating perspective on the persistence of human vulnerability."
—Peter D. Kramer, author of *Listening to Prozac*

Why We Get Sick

The New Science of Darwinian Medicine

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fit. Darwinism gives no moral guidelines about how we should live or how doctors should practice medicine. A Darwinian perspective on medicine can, however, help us to understand the evolutionary origins of disease, and this knowledge will prove profoundly useful in achieving the legitimate goals of medicine.

2

Evolution by Natural Selection

> Now, as each of the parts of the body, like every other instrument, is for the sake of some purpose, viz. some action, it is evident that the body as a whole must exist for the sake of some complex action.
>
> —Aristotle

The solutions to the mysteries discussed in Chapter 1 are to be found in the workings of natural selection. The process is fundamentally very simple: natural selection occurs whenever genetically influenced variation among individuals affects their survival and reproduction. If a gene codes for characteristics that result in fewer viable offspring in future generations, that gene is gradually eliminated. For instance, genetic mutations that increase vulnerability to infection, or cause foolish risk taking or lack of interest in sex, will never become common. On the other hand, genes that cause resistance to infection, appropriate risk taking, and success in choosing fertile mates are likely to spread in the gene pool, even if they have substantial costs.

A classic example is the spread of a gene for dark wing color in a British moth population living downwind from major sources of air pollution. Pale moths were conspicuous on smoke-darkened trees and easily caught by birds, while a rare mutant form of moth whose color more closely matched that of the bark escaped the predators' beaks. As the tree trunks became darker, the mutant gene spread rapidly and largely displaced the gene for pale wing color. That is all there is to it. Natural selection involves no plan, no goal, and no direction—just genes increasing and decreasing in frequency depending on whether individuals with those genes have, relative to other individuals, greater or lesser reproductive success.

The simplicity of natural selection has been obscured by many misconceptions. For instance, Herbert Spencer's nineteenth-century catch phrase "survival of the fittest" is widely thought to summarize the process, but it actually promotes several misunderstandings. First of all, survival is of no consequence in and of itself. This is why natural selection has created some organisms, such as salmon and annual plants, that reproduce only once, then die. Survival increases fitness only insofar as it increases later reproduction. Genes that increase lifetime reproduction will be selected for even if they result in reduced longevity. Conversely, a gene that decreases total lifetime reproduction will obviously be eliminated by selection even if it increases an individual's survival.

Further confusion arises from the ambiguous meaning of "fittest." The fittest individual, in the biological sense, is not necessarily the healthiest, strongest, or fastest. In today's world, and many of those of the past, individuals of outstanding athletic accomplishment need not be the ones who produce the most grandchildren, a measure that should be roughly correlated with fitness. To someone who understands natural selection, it is no surprise that parents are so concerned about their children's reproduction.

A gene or an individual cannot be called "fit" in isolation but only with reference to a particular species in a particular environment. Even in a single environment, every gene involves compromises. Consider a gene that makes rabbits more fearful and thereby helps to keep them from the jaws of foxes. Imagine that half of the rabbits in a field have this gene. Because they do more hiding and less eating, these timid rabbits might be, on average, a bit less well fed than their bolder companions. If, hunkered down in the March snow waiting for spring, two thirds of them starve to death while this is the fate of only one third of the rabbits who lack the gene for fearfulness, then, come spring, only a third of the rabbits will have the gene for fearfulness. It has been selected against. It might be nearly eliminated by a few harsh winters. Milder winters or an increased number of foxes could have the opposite effect. It all depends on the *current* environment.

Natural Selection Benefits Genes, Not Groups

Many people have seen the nature film in which droves of starving lemmings jump eagerly to a watery death as a resonant voice explains that when food becomes scarce, some lemmings sacrifice themselves so that there will be enough food for at least some of the group to survive. A few decades ago, such "group selection" explanations were taken seriously by professional biologists, but not now. To see why, compare two imaginary lemmings. One is a noble fellow who, upon sensing that the population is about to outrun its food supply, quickly jumps to his death in the nearest stream. The other is a selfish lout who waits for the noble ones to do away with themselves and then eats as much food as he can get, mates as often as possible, and has as many offspring as possible. What would happen to the genes that code for the behavior of sacrificing oneself for the benefit of the group? No matter how beneficial they might be for the species, they would be eliminated.

So how can we explain the observations of apparently suicidal lemmings? When food becomes scarce in late winter, lemmings migrate, rushing along in large groups that do not always stop when they encounter waters created by early snowmelt. Drownings are, however, rather uncommon. To get the footage they wanted, the makers of the film apparently had to use brooms to surreptitiously herd the lemmings into the water, a dramatic example of the human preference for altering reality rather than theory when the two conflict! There are special circumstances in which selection at the group level can outweigh the usually stronger force of selection at the level of the individual, but they do not apply very often.

As British biologist Richard Dawkins, author of *The Selfish Gene*, has emphasized, individuals may be viewed as vessels created by genes for the replication of genes, to be discarded when the genes are through with them. This perspective mightily shakes the common view that evolution tends toward a world of health, harmony, and stability. It does not create such a world. We would like to imagine that life is naturally happy and healthy, but natural selection cares not a whit for our happiness, and it promotes health only when it is in the interests of our genes. If tendencies to anxiety, heart failure, nearsightedness, gout, and cancer are somehow associated with increased reproductive success, they will be selected for and we will suffer even as we "succeed," in the purely evolutionary sense.

Kin Selection

We have implied that reproduction is the essence of the fitness maximized by natural selection, and in our discussion of lemmings we indicated that evolution does not favor individuals who act to help others at their own expense. These generalizations tell only part of the story. Ultimately, it is the genetic representation in future generations that counts, whether that is accomplished by having children or by doing things that increase the reproduction of your close relatives, many of whose genes are identical to yours.

Half of the genes in a child are identical to those in the mother, and half are identical to those in the father. Full siblings, on average, also share half of each other's genes. One fourth of the genes in a grandparent are identical to those in the grandchild. Cousins share one eighth of their genes. This means that, from the perspective of your genes, your sister's survival and reproduction are half as important as your own and your cousin's one eighth as important. For this reason, selection favors extending help to relatives if, all else being equal (e.g., age and health), the cost to oneself of extending the help is less than the benefit to the relative times the degree of relationship. In a classic anecdote, British biologist J. B. S. Haldane was asked if he would sacrifice his life for his brother. "No," he said, "not for one brother. But I would for two brothers. Or eight cousins." Formal recognition of this principle and its importance in explaining cooperation awaited the landmark 1964 paper by British biologist William Hamilton, winner of the 1993 Crafoord Prize, created to honor scientists whose work is in fields not covered by the Nobel Prize. Another great British biologist, John Maynard Smith, christened the phenomenon *kin selection*.

Another apparent exception to the nice-guys-finish-last principle in evolution is the result of reciprocal exchanges of favors between individuals who need not be relatives. If Elsa is an expert maker of shoes and Fritz is a skillful hunter of animals that supply excellent

leather, trading resources will benefit them both. It pays me to be nice to you, and vice versa. Ever since Robert Trivers's classic 1971 paper on reciprocity theory, biologists have routinely interpreted cooperative relations among organisms in nature as resulting from either reciprocal exchanges or kin selection. The biology of social life has grown thanks to the efforts of pioneers such as E. O. Wilson, author of *Sociobiology*, and Richard Alexander, author of *Darwinism and Human Affairs*. Early controversies and misunderstandings have been largely supplanted by growing work in this new field of science.

How Does Natural Selection Operate?

There is a widespread misconception that evolution proceeds according to some plan or direction, but it has neither, and the role of chance ensures that its future course will be unpredictable. Random variations in individual organisms create tiny differences in their Darwinian fitness. Some individuals have more offspring than others, and the characteristics that increased their fitness thereby become more prevalent in future generations. Once upon a time (at least) a mutation occurred in a human population in tropical Africa that changed the hemoglobin molecule in a way that provided resistance to malaria. This enormous advantage caused the new gene to spread, with the unfortunate consequence that sickle-cell anemia came to exist, as will be discussed in later chapters.

Chance can influence the outcome at each stage: first in the creation of a genetic mutation; second in whether the bearer lives long enough to show its effects; third in chance events that influence the individual's actual reproductive success; fourth in whether a gene, even if favored in one generation, is, by happenstance, eliminated in the next; and finally in the many unpredictable environmental changes that will undoubtedly occur in the history of any group of organisms. As Harvard biologist Stephen Jay Gould has so vividly expressed it, if one could rewind the tape of biological history and start the process over again, the outcome would surely be different. Not only might there not be humans, there might not even be anything like mammals.

We will often emphasize the elegance of traits shaped by natural selection, but the common idea that nature creates perfection needs to be analyzed carefully. The extent to which evolution achieves perfection depends on exactly what you mean. If you mean "Does natural selection always take the best path for the long-term welfare of a species?" the answer is no. That would require adaptation by group selection, and this is, as noted above, unlikely. If you mean "Does natural selection create every adaptation that would be valuable?" the answer again is no. For instance, some kinds of South American monkeys can grasp branches with their tails. This trick would surely also be useful to some African species, but, simply because of bad luck, none have it. Some combination of circumstances started some ancestral South American monkeys using their tails in ways that ultimately led to an ability to grab onto branches, while no such development took place in Africa. Mere usefulness of a trait does not necessarily mean that it will evolve.

There is a sense, however, in which natural selection does regularly come close to perfection, and that is in optimizing some quantitative features. If a trait serves a specific function, selection among minor modifications over many generations tends to make its quantitative aspects closely approach the functional ideal. For instance, a bird's wings must be long enough to give good lift but short enough to allow the bird to maintain control. Measurements on birds found killed after a major storm showed more than expected numbers of unusually long or unusually short wings. The survivors showed a bias toward intermediate (more nearly optimal) wing lengths.

In human physiology, there are hundreds of similar examples in which traits have been shaped to nearly optimal values: the sizes and shapes of bones, blood pressure, glucose level, pulse rate, age at onset of puberty, stomach acidity—the list could go on and on. The observed values may never be exactly perfect, but they usually come close. When we think that natural selection has erred, it is more likely that we have missed some important consideration. For instance, stomach acid aggravates ulcers, yet people who take antacids can still digest their food. So is there too much acid? Probably not, given the importance of stomach acid in digestion and in killing bacteria, including those that cause tuberculosis. To identify the imperfections of the body, one must first understand its perfections and the compromises on which many of them are based.

Like any engineer, evolution must constantly compromise. An auto designer could increase the thickness of the fuel tank in order to decrease the risk of fire, but at some point increased cost and decreased mileage and acceleration require a compromise. Thus, fuel tanks do rupture in some collisions, and this compromise costs some lives each year. While natural selection cannot achieve perfection in every character simultaneously, its compromises are not random but are accurately shaped to give the greatest net benefit.

An apocryphal story tells of Henry Ford looking at a junkyard filled with Model Ts. "Is there anything that never goes wrong with any of these cars?" he asked. Yes, he was told, the steering column never fails. "Well then," he said, turning to his chief engineer, "redesign it. If it never breaks, we must be spending too much on it." Natural selection similarly avoids overdesign. If something works well enough that its deficiencies do not constitute a selective force, there is no way natural selection can improve it. Thus, while every part of the body has some reserve capacity to deal with occasionally encountered extreme circumstances, every part is also vulnerable when its reserve capacity is exceeded. There is nothing in the body that never goes wrong.

Moderate increments of a resource often have enormous value, while higher amounts may have less benefit. If you are making a stew, two onions may be better than one, but ten onions would be much more expensive yet offer little, if any, extra benefit. Such cost-benefit analyses are routine procedures in economics, but they are useful in biology and medicine as well. Consider the use of an antibiotic for pneumonia. A tiny dose will probably have no detectable benefit, a moderate dose will cost more but offer much greater benefits, while a high dose will have still higher costs with no additional benefits and perhaps significant danger.

Just as there are costs as well as benefits involved in every engineering or medical decision, there are costs associated with every beneficial genetic change preserved in evolution. Natural selection isn't weak or capricious; it just selects for genes that give an overall fitness advantage, even if those same genes increase vulnerability to some disease. Is there any way, for instance, for anxiety to be a functionally desirable trait? Consider what would happen to those rabbits we discussed if they had no anxiety in a year when foxes were especially abundant. Even some genes that cause aging are not necessarily maladaptive. They may give benefits during the early years of life, when selection is the strongest, benefits that are more important to fitness than the later costs of aging and inevitable death. To understand disease better, we need to understand the hidden benefits of apparent mistakes in design.

TESTING EVOLUTIONARY HYPOTHESES

This chapter started with a quotation from Aristotle for a serious reason. We can think of him as the originator of the general procedure for functional analysis that has been particularly fruitful in many kinds of biological research and that we expect to be similarly rewarding in medicine. There is, of course, a big difference between Aristotle's outlook and that of modern biologists. He had almost no grasp of the physical and chemical principles that underlie the workings of any organism. He didn't think experiments were necessary. He had no notion of the principle of natural selection and certainly did not realize that organisms were designed entirely to maximize their success in reproduction. Whether applied to the human hand or brain or immune system, Aristotle's powerful question, "What is it for?" now has a very specific scientific meaning: "How has this trait contributed to reproductive success?" His conviction that the body as a whole exists for the sake of some complex action is correct. Only in the past few decades has it become clear that that complex action is reproduction.

Many people have the notion that questions about the function of a trait are not scientific, that they are "teleological" or "speculative" and therefore not appropriate objects of scientific inquiry. This idea is incorrect, as many examples in this book will demonstrate. Questions about the adaptive function of a biological trait are just as amenable to scientific inquiry as are questions about anatomy and physiology. It makes sense to ask about the adaptive significance of biological traits such as eyes, ears, and the cough reflex because they are products of historical processes that have gradually modified them in ways that improve their capacity to serve special functions.

Yet when we ask these "why" questions, we must guard against too readily believing fanciful stories. Why do we have prominent noses? It must be to hold up eyeglasses. Why do babies cry for no

apparent reason? It must be to exercise their lungs. Why do we nearly all die by age 100? It must be to make room for new individuals. Almost anything can be the subject of such speculation, but if this is as far as it goes it is not science. The problem is not in the questions but in a lack of adequate investigation and critical thinking about suggested answers.

The above absurd examples demonstrate how easily some explanations can be tested and proven false. Noses could not have evolved to hold up glasses, since we had noses long before we had eyeglasses. Crying cannot be to develop the lungs, since lung health in adulthood does not require crying in infancy. Aging cannot have evolved to make room for new individuals, because natural selection cannot favor such benefits to the group and the details of aging simply do not conform to the expectations for such a function.

Other functional hypotheses are so easily supported that they are of little interest. Anyone thoroughly familiar with the heart's structure and operation can see that it pumps blood. One can also see that coughing expels foreign material from the respiratory tract and that shivering increases body heat. You don't need to be an evolutionary scientist to figure out that teeth allow us to chew food. The interesting hypotheses are those that are plausible and important but not so obviously right or wrong. Such functional hypotheses can lead to new discoveries, including many of medical importance.

THE ADAPTATIONIST PROGRAM

Studies of the functional reasons for human attributes are based on a method of investigation recently named the *adaptationist program*. By suggesting the functional significance of some known aspect of human biology, you may logically be able to predict some other, unknown aspects. An appropriate investigation can then confirm that these characteristics are either there or not. If they are there, they may be of medical significance. If they're not, we can eliminate our hypothesis and go back to the drawing board.

We will give three examples here of interesting discoveries made by considering questions on how various features might contribute to fitness. They relate to beavers and birds but not to medical questions, for which we will give many examples in the chapters to come. To various degrees these examples show that intuitive ideas about fitness, even the intuitions of professional biologists, may not always be adequate. Serious, often mathematical, theorizing is needed to provide the logical answers that can then be tested by investigating real organisms.

Beavers harvest trees in or near their ponds for their food and shelter. They use their teeth to chop through the trunks near the ground, drag the trees to the water if they are not already in it, and tow them to their lodges. How do beavers decide which trees to chop down? They do so *adaptively*, was the hypothesis considered by Michigan biologist Gary Belovsky. This implies an economically rational decision based on a tree's likely value to a beaver, the difficulty expected in chopping it down and moving it, and how far it is from home. Belovsky's calculations showed that an efficient beaver ought to be increasingly discriminating as the distance from the pond increases. Small trees may be rejected for not being worth the time to transport them, large ones for not being worth the labor of felling and transporting them, especially dragging them or pieces of them through the woods to where they can be floated in the pond. Belovsky predicted that the range of sizes of trees harvested by beavers would steadily decrease as the distance from the pond increased. At some point, only trees of an ideal size would be harvested; beyond that, none at all. Observation of stumps of beaver-felled trees near their ponds confirmed the prediction. The next time you see a beaver pond, admire not only the beaver's legendary industry but also its cleverness at setting priorities.

Now imagine a woodland songbird about to lay a clutch of eggs that she and her mate will incubate. Her reproductive success for this breeding season will depend entirely on those eggs. How many should she lay? Remember, she is not trying to assure the survival of the species, she is trying to maximize her own lifetime reproductive success. Laying too few eggs would obviously be foolish, but laying too many can also decrease her total lifetime reproduction if there is not enough food and some of the chicks die, or if she exhausts her energy reserves in caring for her brood and thus jeopardizes her chances of living until the next breeding season. These considerations apply equally to every individual in the woodland, but different birds reach different decisions on how many eggs to lay. If the average for a species is four eggs per pair, some pairs may have five and some only three. Do we conclude that all are trying for four but some can't

count? Or do we perhaps conclude that egg numbers are not subject to optimization by natural selection?

An adaptationist forgoes such explanations until after considering the possibility that the birds deserve more credit. Could it be that, as a general rule, three eggs is best for those that lay only three, four for those that lay four, and so on? A simple sort of experiment provides the answer. If there are thirty nests with four eggs, leave ten randomly selected nests alone. From ten other nests remove an egg (the owners are now down to three) and add them to the ten remaining nests (four-egg birds now have five eggs). Now measure the average success of the three groups of birds: those allowed to choose their own egg number and those with one more or one less than they originally laid.

If all relevant factors are carefully considered, the results of such studies usually vindicate the conclusion reached fifty years ago by Oxford ornithologist David Lack: birds adjust the number of eggs they lay to maximize their individual reproductive success. To do this requires an accurate assessment of their own individual health and capabilities and experience. Having to provide food for four nestlings is more difficult and hazardous than providing for only three. Nestlings in more crowded nests may weigh less at fledging and be less likely to survive the following winter. Conditions vary unpredictably from year to year, and worse-than-normal years are especially dangerous for the more crowded broods. Surely such knowledge enhances a naturalist's pleasure in watching a pair of wild birds feed their young. Those birds are doing it right—not just right in general or on average, but right for them as unique individuals.

In this discussion of clutch size we considered the optimal number of offspring. We ignored the fact that there are two kinds of offspring, male and female. Should our birds ideally produce one or the other or both in some ideal proportion? In the natural selection of sex ratio one overwhelmingly important strategy maximizes fitness: producing offspring of whichever sex is in short supply. Any frequenter of singles bars knows that the minority sex has a mating advantage. In nature, individuals that produce male offspring when females are scarce will be selected against because many of those males will never have offspring. If males are scarce, individuals that produce females will not have as many grand-offspring as individuals who produce males. The operation of this process of selection explains why there are equal numbers of males and females. This simple, elegant evolutionary explanation was first recognized by the great evolutionary geneticist

R. A. Fisher in 1930. If you are thinking that an equal sex ratio arises because an individual has an equal chance of getting an X or a Y chromosome from its father, you are right, but this is a proximate explanation. The insufficiency of a proximate explanation is demonstrated by the many special cases such as ants and fig wasps, which are too complex to describe here but in which grossly unequal sex ratios turn out to match the more complex predictions.

Does natural selection in fact produce populations with exactly the same number of males and females? No, it does not, as would be expected by detailed reflection on factors such as the two sexes reaching maturity at different ages, differing death rates, differing costs to male and female parents, and other factors. Careful calculations support the conclusion that, for organisms with sex-determination and reproductive processes like ours, the sex ratio will stabilize when the parents collectively spend equal resources on rearing sons and rearing daughters. The demography of human and many other populations conforms closely to these expectations.

We hope to convince you in the coming chapters that the modern theory of natural selection can be just as helpful in making medically important discoveries as it is for predicting the foraging patterns of beavers, the effects of altered clutch sizes of birds, and the sex ratios of mammals. The reasoning will always start with some prior information about health or disease and a question about evolved adaptation: Is this feature of the human body a part of some adaptive machinery? If so, what must the rest of the machinery be like? How can we test our predictions for unknown aspects of the machinery? If any feature of human biology seems functionally undesirable, how can natural selection have permitted it to arise? Is an undesirable trait the price of a positive feature? Could it be a trait that was adaptive in the Stone Age but that now causes disease? What are the medical consequences of natural selection acting to improve adaptation in our pathogens and parasites? These are just a few of the sorts of questions now routinely asked by evolutionary biologists, and efforts at answering them have been enormously fruitful.

We must temper our enthusiasm with a note of caution. A question about function can have more than one right answer. For instance, the tongue is important both for chewing and for speech; the eyebrows, both for keeping the sweat out of the eyes and for communication. Second, the evolutionary history of a species or a disease is like any other kind of history. There is no experiment, in the usual

sense, that we can do now to decide how long ago our ancestors first started to use fires for cooking or other purposes and what subsequent evolutionary effects that change may have had. History can be investigated only by examining the records it has left. Charred bones or even carbon deposits from an ancient campfire can be informative documents to people who know how to read them. Likewise, the chemical structure of proteins and DNA may be read to reveal relationships among now strikingly different organisms. Until a time machine is invented, we will not be able to go back and watch the evolution of major traits, but we can nonetheless reconstruct prehistoric events by the records they left in fossils, carbon traces, structures, and behavioral tendencies, as well as protein and DNA structures. Even when we cannot reconstruct the history of a trait, we can often still be confident that it was shaped by natural selection. This can be supported by evidence for its function in other species and by the match between the trait's characteristics and its functions.

So hypotheses about the evolutionary origins and functions of a trait, just like hypotheses about proximate aspects of a trait, need testing and are often testable. Special difficulties attend the testing of evolutionary hypotheses, but these are no reason to give up—they just make the work more challenging and interesting. Do we claim to test evolutionary hypotheses in this book? Not really. While we will try to separate speculation from fact, and will cite evidence for most of our examples, hardly any of them can be considered proven by the evidence we present. Some of the examples are based on many studies, each with different data bearing on a different aspect of the problem, but even this is often insufficient.

Our goal is not to prove any specific hypothesis but to show that evolutionary questions are interesting, important, and testable. We want people to start asking new questions. So, without apology, we ask questions about the possible evolutionary significance of diverse aspects of disease and offer answers that are often speculative. Some people will, despite our warnings, insist on taking these speculations as facts. Perhaps in a few years Darwinian medicine will have enough confirmed findings to fill a book. For now, our goal is not to exhaustively test a few hypotheses but to encourage patients, doctors, and researchers to ask new questions about why disease exists. As Gertrude Stein said on her deathbed, "The answer, the answer, the answer. What is the answer? . . . In that case, what is the question?"

not that gerontologists give up their efforts to extend the life span, only that they conduct them in the light of evolution.

We should also note that pessimistic assessments of what science can accomplish often have substantial utility. They provide what philosopher E. T. Whittaker called *postulates of impotence*. Because of such pessimism, engineers no longer try to design perpetual-motion machines and chemists no longer try to turn lead into gold. If gerontologists stop trying to find the fountain of youth in some single, controllable cause of senescence, their efforts may prove more fruitful for human well-being.

The clinician has more immediate concerns. The proportion of people over the age of eighty-five is growing six times faster than the population as a whole. In just the past three decades, the average life expectancy in the United States has gone from 69.7 to 75.2 years. More than a quarter of every health care dollar is now spent on patients in the last year of life, and the need for nursing home beds is expected to quadruple in the next twenty years. Medicine has changed its focus from acute diseases of children and younger adults to chronic diseases of the elderly. Doctors who imagined spending their careers giving antibiotics to stop pneumonia and doing heroic curative surgery now find themselves monitoring high blood pressure, evaluating memory problems, and relieving the symptoms of chronic heart disease. Many of these physicians and their patients still think of senescence as a disease. We expect that knowledge about the evolutionary origins of senescence will have profound effects that are difficult to predict.

This perspective may also change how we see our own lives. Some may find it a consolation to know that senescence is the price we pay for vigor in youth. There is also relief as well as disappointment in knowing that no medical advance is ever likely to extend our lives to any dramatic extent. The search for some pill or exercise or diet that can save us from senescence may be replaced by an appreciation of life as it is, of vigorous function at whatever age. The preoccupation with living forever is likely to be supplanted by a desire to live as fully as possible, while it is possible.

9

Legacies of Evolutionary History

The past! the past! the past!
The past—the dark unfathom'd retrospect!
The teeming gulf—the sleepers and the shadows!
The past—the infinite greatness of the past!
For what is the present after all but a growth out of the past?

—"Passage to India" by Walt Whitman

Phil, the unfortunate television weatherman who lives one day over and over again in the movie *Groundhog Day*, enters a restaurant just as a diner begins to choke on a bite of food. Phil, having observed this scene many times before, calmly steps behind the gasping man, wraps his arms around the man's upper abdomen, and suddenly squeezes hard. The food is expelled from the diner's windpipe and he can breathe again, his life saved by Phil and the Heimlich maneuver.

About one person in a hundred thousand chokes to death each year. While this death rate is small compared to that from automobile accidents, choking has been a persistent cause of death not only throughout human evolution but throughout vertebrate evolution because all vertebrates share the same design flaw: our mouth is below and in front of our nose, but our food-conveying esophagus is behind the air-conveying trachea in our chest, so the tubes must cross in the throat. If food blocks this intersection, air cannot reach our lungs. When we swallow, reflex mechanisms seal off the opening to the trachea so that food does not enter it. Unfortunately, no real-life machinery is perfect. Sometimes the reflex falters and "something goes down the wrong pipe." For this contingency we have a defense, the choking reflex, a precisely coordinated pattern of muscular contractions and tracheal constriction that creates a burst of exhaled air to forcibly expel misdirected food. If this backup mechanism fails and an obstruction blocking the trachea is not dislodged, we die—unless, that is, Phil or someone like him happens to be nearby.

But why do we need the protective mechanisms of traffic control and a backup choking reflex? It would be so much safer and easier if our air and food pathways were completely separate. What functional reason is there for this crisscross? The answer is simple—none at all. The explanation is historical, not functional. Vertebrates from fish to mammals are all saddled with an intersection of the two passages. Other animal groups, such as insects and mollusks, have the more sensible arrangement of complete separation of respiratory and digestive systems.

Our air-food traffic problem got started by a remote ancestor, a minute wormlike animal that fed on microorganisms strained from the water through a sievelike region just behind the mouth. The animal was too small to need a respiratory system. Passive diffusion of dissolved gases between its innermost parts and the surrounding water easily supplied its respiratory needs. Later, as it evolved a larger size, passive diffusion was ever less adequate, and a respiratory system evolved.

If evolution proceeded by implementing sensible plans, the new respiratory system would have been just that, a new system designed from scratch, but evolution does no sensible planning. It always proceeds by just slightly modifying what it already has. The food sieve at the forward end of the digestive system already exposed a large surface area to a flowing current. With no special modifications, it was already serving as a set of gills by providing a large proportion of the needed gaseous exchanges between internal tissues and environment. Additional respiratory capacity was created by slow modifications of

this food sieve. Rare minor mutations that made it slightly more effective in respiration were gradually accumulated over evolutionary time. Part of our digestive system was thereby coopted to serve a new function—respiration—and there was no way to anticipate that this would later cause great distress in a Pennsylvania restaurant on Groundhog Day. Today, the food-sieving worm stage in our evolution is still found in the closest invertebrate relatives of modern vertebrates, which have combined respiratory and digestive passages, as shown in Figure 9-1.

Much later, the evolution of air breathing caused some other evolutionary changes that we now have cause to regret. When part of the respiratory region was modified to form a lung, it branched off the lower side of the esophagus that led to the stomach. Accessory openings for air breathing at the surface of the water evolved, understandably, from the already available olfactory organs (nostrils) on the upper surface of the snout, not on the chin or throat. So the air passage opened above the mouth opening and led into the forward part of the digestive tract. Air then passed back through the mouth and larynx to where the trachea branched off and went through this passage to the lungs. This is the lungfish stage (see Figure 9-2).

Subsequent evolution moved the connection from the nostrils back into the throat so that the air passage was as completely separate from the digestive system as it could become without redesigning the structure of the head and throat. Thus a long dual-function passage was gradually shortened until only the crisscross remained, but we and all higher vertebrates are still stuck with it. Vertebrates have the unenviable capacity to be asphyxiated by their food. Darwin pointed out, in 1859, how difficult it is, from a purely functional perspective, to

> understand the strange fact that every particle of food and drink which we swallow has to pass over the orifice of the trachea, with some risk of falling into the lungs, notwithstanding the beautiful contrivance by which the glottis is closed.

We are actually worse off than other mammals because traffic control in our throat is further compromised by modifications to

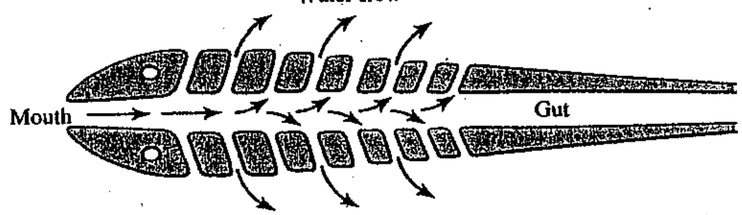

FIGURE 9–1.
Diagram of respiratory and digestive passages of a larval tunicate, and of the extinct ancestor of all vertebrates, as seen in a horizontal section through the forward end of the body.

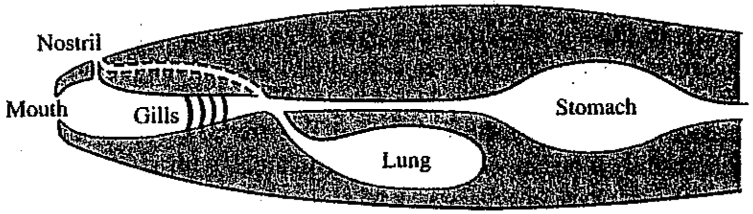

FIGURE 9–2.
The lungfish stage of the evolution of respiratory and digestive systems of higher vertebrates, as seen in a vertical section to one side of the midline. The dotted lines show the later shift of the nostril connection to the crossing in the throat, as is found in mammals.

facilitate speech. Did you ever watch a horse drinking? It keeps its mouth in the water and drinks without interrupting its breathing. It can do this because the opening from its nasal region can be precisely lined up with the opening into the trachea. The respiratory passage forms a sort of bridge across the digestive passage, so that when the horse swallows, it can make use of space to the left and right of the bridge. Unfortunately for us, our tracheal opening has slipped further back in the throat, so that the bridge connection can no longer be made. At least not for adults; babies, for the first few months of life, can swallow liquids and breathe simultaneously, like many other mammals. Once they start making the babbling that is the precursor of human speech, however, they can no longer drink like horses. The human capacity for choking represents an ancient maladaptive legacy aggravated by a much later compromise.

OTHER MALFUNCTIONAL DESIGN FEATURES

Many other serious design flaws make us susceptible to medical problems. Perhaps the most often recognized is the inside-out retina. Vertebrate eyes started as light-sensitive cells under the skin of a minute transparent ancestor. The blood vessels and nerves that served these light-sensitive cells came from the outside, as good a direction as any, for a transparent animal. Now, hundreds of millions of years later, light still must pass through these nerves and blood vessels on the surface of the retina before it reaches the rods and cones that react to the light. The nerve fibers of the retina gather into a bundle, the optic nerve, which must exit the eye to get to the brain. At the hole where the optic nerve exits the retina, there can be no rods and cones. This causes the eye's blind spot. To demonstrate it, close your left eye and focus your right eye straight ahead at the eraser end of a pencil. Move the pencil to the right without letting the eye follow it. The eraser will disappear at a spot about twenty degrees from the forward line of vision. The left eye is similarly blind twenty degrees to the left of its midline.

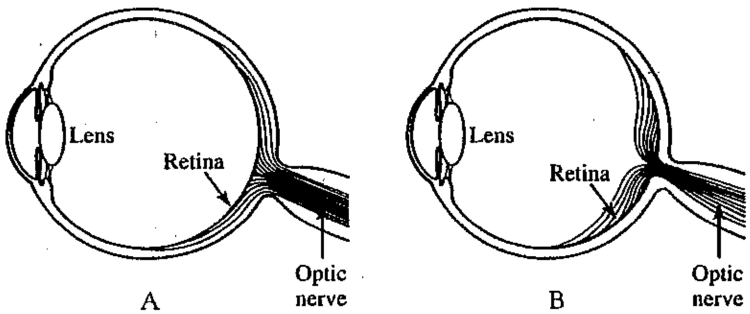

FIGURE 9–3.
A. The human eye as it ought to be, with a squid-like retinal orientation.
B. The human eye as it really is, with nerves and vessels traversing the inside of the retina.

The blood vessels on the retina create another problem. They cast shadows that create a network of blind spots on the retina. To overcome this, our eyes move constantly in tiny twitches so that they scan slightly different areas every fraction of a second. This mass of information is processed in the brain, which compiles it into a coherent image. We are deceived into thinking we see something continuously with both eyes when we may only be seeing it intermittently with one. Nevertheless, the shadows, like the blind spot, are always there. To demonstrate this useful self-deception, go into a dark room, press the light end of a penlight against the side of your closed eyelid, turn it on, and gently wiggle it around. When the lineup is exactly right, you will see the shadow of the intricately branching system of parallel veinlets and arterioles that supply the retina.

The inversion of the retina is a universal defect in vertebrates that makes no functional sense. As with the unfortunate intersection between the passages for food and air, the explanation is historical, and it applies only to the vertebrates. The functionally analogous eye of a squid has a more sensibly oriented retina with the nerves and blood vessels coming from behind the retina. The squid eye does not need secondary contrivances to minimize the

effect of the design flaw that plagues vertebrates, any more than it need worry about eating interfering with breathing. The squid and other mollusks have their own suites of malfunctional historical legacies.

Our inverted retina is responsible not only for slight visual impairment but also for some special medical problems. Any bleeding or minor obstruction of blood flow in the retina casts a shadow that may seriously impair the visual image. Still more serious is the ease with which the light-gathering surface (rods and cones) can lift loose from the underlying interior of the eyeball. Once this condition of *detached retina* gets started, it is a dire emergency that, if untreated, can lead to blindness. The more sensibly designed squid eye, by contrast, has its retina anchored securely from below by numerous nerve fibers so that it cannot become detached.

In addition to those flaws, which affect all vertebrates or all mammals, there are some that affect only humans, or only humans and our closest primate relatives. The appendix is an example. People who recover from appendectomies seem to suffer no disadvantage from not having this part of the human body. The only functional significance of the appendix, as far as we know for sure, is to enable us to have appendicitis. The appendix is the vestige of part of the caecum, a digestive organ in our early mammalian ancestors that helped to process plant foods of low nutritional value. For rabbits and many other mammals, the caecum still serves this function. The shift to a diet of foods with more concentrated nutrition, such as fruit and insects, caused the caecum to degenerate in the course of primate evolution because there was no selection to maintain it. Unfortunately, it has not yet entirely disappeared, and the vestige now makes us vulnerable to appendicitis.

So why does the appendix persist at all? It does make a minor—but by no means important—contribution to the immune system. We also wonder if it might, paradoxically, be maintained by appendicitis. The long, thin shape of the appendix makes it vulnerable when inflammation causes swelling that squeezes the artery to the appendix and cuts off its only blood supply. When filled with bacteria, an appendix without a blood supply cannot defend itself. Bacteria grow rapidly and eventually burst the appendix, spreading infection and toxins throughout the abdominal cavity. A bit of inflammation and swelling is less likely to disrupt the blood supply of a large appendix than that of a long, thin one. Natural selection gradually reduces the size of the useless appendix, but any appendix narrower than a certain diameter becomes more vulnerable to appendicitis. Thus, deaths from appendicitis may paradoxically select for a slightly larger appendix, maintaining this less-than-useless trait. Selection is also almost certainly very slowly making the appendix shorter, but in the meantime the appendix may be maintained by the shortsightedness of natural selection. We wonder if other vestigial traits might also be maintained because further diminishing them increases vulnerability to a disease.

Many primates and most other mammals can make their own vitamin C, but we humans cannot. Our ancestral shift to a high-fruit diet, rich in vitamin C, had the incidental consequence about forty million years ago of allowing the degeneration of the biochemical machinery for making this vitamin. Our frugivorous close relatives share our requirement for dietary vitamin C. All animals need particular organic substances (vitamins) in their food, but different groups have different requirements.

Some of our vulnerability to mechanical damage can also be blamed on various past evolutionary developments. A sharp blow to the side of the human head may fracture the skull, damage the brain, and cause death or permanent impairment. The same blow to an ape head may result merely in a bruised temporalis muscle and temporary impairment of chewing. The difference arises from the increased size of the human brain case and shrinkage of the jaw musculature, which incidentally rob the skull of its earlier cushioning. The hard hats construction workers and cyclists wear are a technological fix for a biological deficiency. If workers and cyclists go on being careless about wearing their hard hats, perhaps in another million years we will again have a thick padding of tissue under our scalps to reduce brain injuries.

The same increased skull size has resulted in a fetal head that fits through a human pelvis only with difficulty. A woman's pelvic structure is slightly different from a man's, so as to provide a large birth passage and, as childbirth approaches, the pubic joint loosens to further facilitate the passage of the infant. Yet childbirth is still more difficult than it would be if the vagina could open outside the massive ring of pelvic bone, perhaps above the pubis on the lower abdomen. The passage of the vagina through the pelvis is a severe historical constraint on the evolution of any further increase in fetal head size. This

constraint, of having to fit an oversize head through the pelvic ring of bone, explains why human babies have to be born at such an early and vulnerable stage of development, compared to, for example, ape babies.

The prevalence of maladaptive human design features has been recognized for a long time. A 1941 book by George Estabrooks, *Man, The Mechanical Misfit*, describes many of the structural defects and compromises in human anatomy, especially those that result from turning a horizontal four-footed animal into an upright two-footed one. The weight of the top part of the body greatly compresses the vertebrae in the lower spine, and standing upright requires more muscular effort than a horizontal posture would. The pelvis was originally designed to resist a back-to-belly force of gravity, not the fore-to-aft force that ours must resist as long as we remain upright, either standing or sitting. Elaine Morgan's recent book *The Scars of Evolution* gives a readable account of these maladaptive legacies.

A long list of medical problems, ranging from minor annoyances to serious disabilities, results from the mechanical inadequacies of our adaptations for an upright posture and two-footed locomotion. Perhaps the most important is the episodic lower back pain experienced by so many people. Our knees, ankles, and feet are also extraordinarily vulnerable. How often do we hear of athletes missing games because of knee and ankle injuries? One of the authors once leaped high in a volleyball game, and when he came down only his left foot was on the court. The right landed on the foot of a teammate and turned sharply inward, seriously straining the vulnerable lateral ligament, which is usually the part that fails when an ankle is sprained. The author met his classes on crutches for the next week and was glad he was not part of a band roving over the Paleolithic savannah. He also regretted that the human ankle is not better designed.

The abdominal viscera of a mammal are enclosed in sheets of tissue designed to hang from the upper wall of the abdominal cavity. This is fine for a mammal on all four legs, but in an upright mammal the sheets of tissue may be said to hang from a vertical pole, a grossly ineffective arrangement that causes such diverse problems as digestive system blockages, visceral adhesions, hemorrhoids, and inguinal hernia. The mammalian circulatory system is also compromised by upright posture. It works fine for a dog or a sheep, but our upright posture increases the hydrostatic pressure in the lower extremities and can cause varicose veins and swollen ankles. The opposite effect, deficient blood pressure in the brain, can result in dizziness or momentary partial blackout when we suddenly stand up from a recumbent position.

Sometimes the body's responses to problems are just the opposite of what would be adaptive. When the heart muscle is too weak to pump all the blood it receives, the blood backs up into the lungs and feet and causes shortness of breath, swollen ankles, and other symptoms of congestive heart failure. You might expect that this would cause excretion of excess fluid, but patients with heart failure retain salt and fluid, and this excess blood volume makes the problem even worse. This response is maladaptive in patients with heart disease, but, as internal medicine physician Jennifer Weil points out, the body's response is designed for a different problem. In a natural environment, most instances of deficient blood pumping would result from bleeding or dehydration, in which the fluid retention mechanism would be useful indeed! Heart failure occurs mainly in old age and mechanisms to conserve body fluid can be useful throughout life, so this system is a fine example of a cause of senescence which is maintained because of its benefits in youth.

We have been discussing defects in the basic plan of the human body. These should not be confused with mere inadequacies of execution and random departures from optimal values. As a general rule for any readily measured physical feature, it pays to be in the middle of the pack, as we illustrated previously with the birds with longer- or shorter-than-average wings, which were especially likely to be killed in a storm. Unusually tall or short people tend not to live as long or as healthily as those of average height. Babies of average birth weight are usually better off than those who are much heavier or lighter. Everyone knows that high or low blood pressure is not as good as normal blood pressure. A high level of adaptive performance usually requires that many quantitative characteristics closely approach optimal values. While no individual is perfect, the various parameters sometimes combine to yield remarkable excellence. Yet even in near perfection there is substantial variation—as is well known to those basketball stars who played against Michael Jordan.

Many design features, while not maladaptive, are functionally arbitrary and explicable only as historical legacies. In mammals, the right side of the heart circulates the blood to the lungs, the left side to the rest of the body. In birds it is the other way around, for no better reason than that birds and mammals came from different reptilian ancestors that took arbitrarily different routes to cardiac specialization. Either way works equally well. Some arbitrary features can be advantageously exploited. Many people who are alive today would be dead except for the happenstance of everyone having two kidneys. When one fails or is donated, the other is able to do double service. By the same logic, many people die of having only one heart. The reason we have two kidneys and one heart is simply that, right from their origins, all vertebrates had two kidneys and one heart. This is pure historical legacy and has nothing to do with the advantage of having two of one organ or the disadvantage of having only one of another.

We have belabored what is wrong or arbitrary with the human body because the design flaws can cause many medical problems, but we hope that our readers will also realize that much about it is just right. Our oversize brains may be vulnerable to injury and may impede childbirth, but they make us the unchallenged leaders of the animal kingdom in cognitive capability and in all the social and technological advances that this makes possible. No other species in the history of our planet has ever controlled its environment to the extent that we have since the invention of agriculture. Similarly, our longevity is impressive in relation to that of any other mammal, except a few, such as elephants, that are far larger than we are. We can live about half again as long as any other primate.

Moreover, many of our other adaptations are equal or superior to those in other mammals. Our immune system is superb. Also, despite conspicuous design flaws and individual imperfections, our eyes and related brain structures incorporate layer upon layer of information-processing marvels that extract the maximum amount of usefulness from visual stimuli. If hawks, for example, have visual acuity that is in some ways superior to ours, this one kind of superiority must be purchased with some kind of trade-off. Animals that can see better than we can in the dark cannot see as well in the light. Normal human vision approaches a theoretical maximum of sensitivity and discrimination over a wide range of conditions. We are only beginning to understand how it is that a face, seen from one angle at a certain distance, may later, from another angle and distance, be instantly recognized. No current computer can approach such feats. Our hearing is so sensitive to some frequencies that if it were more sensitive we would not hear as well. Informative sounds would be lost in the noise of random air molecules colliding with our eardrums.

The Finishing Touch

We have been discussing mainly attributes that humans share with other vertebrates, other mammals, or other primates. Our discussions of our problems with upright stature also apply to extinct members of our genus, *Homo*. We now turn to more explicitly human legacies, with an emphasis on the evolutionary adjustments made in the period from about one hundred thousand to about ten thousand years ago. While natural selection has been changing us in many small ways in the last ten thousand years, this is but a moment on the scale of evolutionary time. Our ancestors of ten thousand or perhaps even fifty thousand years ago looked and acted fully human. If we could magically transport babies from that time and rear them in modern families, we could expect them to grow up into perfectly modern lawyers or farmers or athletes or cocaine addicts.

The point of the rest of this chapter, and the following one, is that we are specifically adapted to Stone Age conditions. These conditions ended a few thousand years ago, but evolution has not had time since then to adapt us to a world of dense populations, modern socioeconomic conditions, low levels of physical activity, and the many other novel aspects of modern environments. We are not referring merely to the world of offices, classrooms, and fast-food restaurants. Life on any primitive farm or in any third-world village may also be thoroughly abnormal for people whose bodies were designed for the world of the Stone Age hunter-gatherer.

Even more specifically, we seem to be adapted to the ecological and socioeconomic conditions experienced by tribal societies living in the semiarid habitat characteristic of sub-Saharan Africa. This is

most likely where our species originated and lived for tens of thousands of years and where we spent perhaps 90 percent of our history after becoming fully human and recognizable as the species we are today. Prior to that was a far longer period of evolution in Africa in which our ancestors' skeletal features lead scientists to give them other names, such as *Homo erectus* and *Homo habilis*. Yet even these more remote ancestors walked erect and used their hands for making and using tools. We can only guess at many aspects of their biology. Speech capabilities and social organizations are not apparent in stone artifacts and fossil remains, but there is no reason to doubt that their ways of life were rather similar to those of more recent hunter-gatherers.

Technological advances later allowed our ancestors to invade other habitats and regions, such as deserts, jungles, and forests. Beginning about one hundred thousand years ago, our ancestors began to disperse from Africa to parts of Eurasia, including seasonally frigid regions made habitable by advances in clothing, habitation, and food acquisition and storage. Yet despite the geographic and climatic diversity, people still lived in small tribal groups with hunter-gatherer economies. Grainfield agriculture, with its revolutionary alteration of human diet and socioeconomic systems, was practiced first in southwest Asia about eight thousand years ago and shortly thereafter in Egypt, India, and China. It took another thousand years or more to spread to central and western Europe and tropical Africa and to begin independently in Latin America. Most of our ancestors of a few thousand years ago still lived in bands of hunter-gatherers. We are, in the words of some distinguished American anthropologists, "Stone Agers in the fast lane."

Death in the Stone Age

Imagine what it must have been like in that idyllic era. You were born into a nomadic band of forty to a hundred people. Whatever its size, it was a stable social group. You grew up in the care of various close relatives. Even if your local band consisted of a hundred or more people, many of them were distant cousins. You knew them all and knew their genetic and marital connections to yourself. Some you loved deeply and they loved you in return. If there were those you did not love, at least you knew what to expect from them, and you knew what everyone expected of you. If you occasionally saw strangers, it was probably at a trading site, and you knew what to expect of them too. In a sparsely peopled world the necessities of life—plant and animal foods uncontaminated by pesticides—were there for the taking. You breathed the pure air and drank the pure water of a preindustrial Eden.

Having asked you to imagine an idyllic past, we now urge that you be more realistic. Like other Golden Age legends, such as the age of chivalry or that delightful antebellum world into which Scarlett O'Hara was born, it is a fabricated myth. Enjoy it in fantasy or fiction, but do not let it mislead serious thought on medicine or human evolution. The unpleasant fact is that our hunter-gatherer ancestors lived with enormous difficulty and hardship. Simple arithmetic on the rates of death and reproduction makes this conclusion inescapable. Death always balanced reproduction, even though people reproduced at something approaching the maximum feasible rate.

In most primitive social systems, women start bearing children as soon as they are able to do so, which, because of nutritional limitations, is often delayed until about age nineteen. Pregnancy and childbirth are followed by two or three years of lactation, which inhibits ovulation. Then the mother is soon pregnant again, whether this is medically advisable or not. In the unlikely event that she remains fully fertile and survives to menopause, she will probably produce about five babies. Having more children would require shortened lactation periods, and this is unlikely given the limited foods available for babies in preagricultural societies.

But even if hunter-gatherer women averaged only four children before succumbing to sterility or death, only half their babies could have survived to maturity. Otherwise the human population would have steadily increased, and this obviously did not happen. Even an increase of 1 percent per century would cause a population to become a thousand times as numerous in less than seventy thousand years, but populations remained extremely sparse until the invention of agriculture. The conclusion is thus quantitatively inescapable that deaths almost precisely kept up with births for nearly all of human history. The extraordinarily low death rates of the last few centuries, and especially in the last few decades in Western societies, show that we live in times of unprecedented safety and prosperity. It is no doubt difficult for most readers of this book to appreciate the harshness and insecurity of human life under natural conditions.

Mortality rates in the Stone Age, like those of today, were highest in infancy and declined throughout childhood. Many early deaths in some groups were from infanticide, motivated by parents' economic hardship or imposed by patriarchs. While fictional accounts of Stone Age conditions probably exaggerate the ravages of predation and other wild-animal attack, lions, hyenas, and venomous snakes were ever-present hazards and took a steady toll, with children especially vulnerable. Death rates from poisoning and accidents were far higher than they are now.

The infectious diseases, which were probably the most important source of mortality for all age groups, were not the same bacterial and viral diseases that afflict us today. Most of today's infections depend on rates of personal contact only possible in abnormally dense populations. Back then, vector-borne protozoa and worms were common causes of prolonged sickness and ultimate death. Many of these diseases are not merely lethal but most unpleasantly so. Some readers will know how unpleasant malaria can be, from personal experience or from knowing someone who has had the disease. It is a lark compared to other protozoan diseases such as kala-azar, which slowly destroys the liver and other viscera; parasites such as lungworms, which cause death by suffocation; hookworms, which are seldom fatal but can make children grow into physically and mentally defective adults; and filaria, which among other things cause elephantiasis. The name comes from the swelling of the limbs and scrotum to elephantine proportions because the parasites block the lymphatic vessels.

Food was often abundant for hunter-gatherers, but memories of bounteous fruit harvests or an occasional big kill must have been a poor solace during the regularly recurring famines. Climatic variations induce fluctuation in resources. Even in the most stable climates, food abundance varies because of plant and animal diseases. Prior to the invention of reliable preservation techniques, temporarily abundant food could not be saved for leaner times. Even foods preserved by drying or smoking could be attacked by pests that could frustrate the most careful planning for future emergencies.

Shortages of vital necessities were not only directly stressful, they also encouraged strife. Imagine that people from a hill tribe were suffering from a protein shortage, while people in the valley were feasting on the abundant fish from their lake. The people from the hills would no doubt insist that their leaders take them to that lake, no matter how loudly the valley people asserted their exclusive fishing rights. If catching the fish means killing the fishermen and appropriating their fishing gear, that is what the hill people might decide to do. Even in the absence of economic necessity, human nature often finds excuses for armed robbery and attendant taking of life. Fortunately for early tribal societies, they lacked the technology of transport and communication that permitted banditry on the scale practiced by Genghis Khan or Alexander of Macedon.

Human nature has, of course, its nobler aspects. There are such things as love and charity and honesty. Unfortunately, the evolutionary origins of such qualities are rooted in their utility in parochial tribal settings. Natural selection clearly favors being kind to close relatives because of their shared genes. It also favors being known to keep one's promises and not cheating members of one's local group or habitual trading partners in other groups. There was, however, never any individual advantage from altruism beyond these local associations. Global human rights is a new idea never favored by evolution during the Stone Age. When Plato urged that one ought to be considerate of all Greeks, not merely all Athenians, it was a controversial idea. Today, humanistic sentiments still face formidable opposition from parochialism and bigotry. In fact, these destructive tendencies are aggravated by what we just now called the "nobler" aspects of human nature. As Michigan biologist Richard Alexander so neatly put it, today's central ethical problem is "within-group amity serving between-group enmity."

Life in the Stone Age

Human nature was formed in what anthropologists have recently termed (following a 1966 suggestion by psychiatrist John Bowlby) the *environment of evolutionary adaptedness*, or *EEA*. Despite their frequent reference to the EEA, anthropologists differ widely about what it was like. They can-

not directly observe the ways of our ancestors of tens of thousands of years ago or the effects of environmental conditions on the human genetic makeup. They must base their conclusions on indirect evidence: skeletal remains, stone tools, cave paintings, and information about modern groups with seemingly primitive economies and social conditions.

The shortage of information is serious. What are the historically normal conditions of human childbirth? This is just one of many basic questions for which there is no assured answer. We suspect that the correct answer to many such questions is, *it was highly variable.* Attitudes toward childbirth differ enormously among different cultures today, and there is no reason to believe they were any less variable a hundred thousand years ago. They must also have been quite variable within social groups. The solicitude offered to a chief's wife no doubt differed from that proffered a concubine captured from a hostile tribe. Giving birth during times of plenty in a settled camp might have been rather different from giving birth in leaner times or during travel to a new location.

We also suggest that the correct answer to other important questions is, *it varied.* What sorts of rewards went to gifted poets, artists, or others of high intellectual attainment, compared to those who were good hunters or warriors? How stratified, by family connections or merit, were the socioeconomic conditions? Was inheritance matrilineal or patrilineal? What were the child-rearing customs? What were the religious doctrines and constraints, and how strong a factor was religion? These questions would have vastly different answers in different societies in the EEA. There is no one "natural" way of human life.

Despite great variation in the human adaptations to a variety of EEA conditions, the available evidence does support some generalizations. Social systems were constrained by economics and demography. No elaborately stratified societies with hereditary class structures were possible in the Stone Age, because groups that had to gather their food from within walking distance necessarily remained small. Likewise, no chief of a nomadic band can have dozens of wives when the band only includes a few dozen people. Prior to the development of agriculture, no chief could control enough land, wealth, and people to build cathedrals or pyramids.

Social systems were also constrained by the physiological and structural differences between the sexes. The physiological costs of reproduction involved in pregnancy and lactation are borne entirely by women. By what rules were the economic costs of reproduction apportioned? Again, we suggest, *they varied*. On the basis of what we know about current human groups, husbands no doubt contributed significantly in most cultures, but in others a mother's brothers and other relatives made a greater contribution. Likewise, the gross physical differences between the sexes imply behavioral differences. The greater size and strength of men suggest that these attributes provided important competitive advantages, especially in the competition for mates. We discuss this and related matters in Chapter 13.

Economic necessity often demanded that adults and older children of both sexes spend much of their time searching for and preparing food. It is usually assumed that men did the hunting and women the gathering in hunter-gatherer societies, although the antiquity and importance of big-game hunting have been exaggerated in fictional accounts of Stone Age life. Archery and other weapons effective against such animals as deer were in fact not invented until late in the Stone Age. Dogs, which can play crucial roles in many hunting techniques, were not common human associates before about fifteen thousand years ago. Meat or hides from large animals may often have been procured not by hunting but by scavenging or stealing from other predators.

The mainstay foods in the Stone Age would seem to us inedible or too demanding of time and effort. We would find most of the game strong-tasting and extremely tough. Most of us have little appreciation of the tedious skinning and butchering it takes to turn a wild animal carcass into a serving of meat. Many wild fruits, even when fully ripe, are sour to our tastes, and other plant products are bitter or have strong odors. We find them unpleasant thanks to our adaptations that make us avoid toxins, as discussed in Chapter 6. Most natural human foods require a far greater labor of preparation and chewing than the foods we eat now. Domesticated animals and plants have been artificially selected to be tender, nontoxic, and easily processed.

Despite the abundance of foods available in the EEA much of the time, the village elders would have been able to remember times of severe famine. Actual starvation may have been rare, but deaths from the combined stresses of disease, malnutrition, and poisoning by the excessive consumption of marginally edible plants were probably

common. These same stresses also would have caused abortion of fetuses, curtailment of lactation, reduced fertility, and actions such as infanticide and the abandonment of the old or impaired.

In addition to xenophobic conflict with other groups, social strife within groups, famines, and toxic diets, there were many other environmental stresses. Our ability to tolerate the atmospheric pollution of modern cities may owe much to our many thousands of years of exposure to smoke toxins from woods and other fuels. Imagine living in a hut with a fire on the floor and only a small hole in the roof. Atmospheric pollution was different in the EEA, but it was substantial and real. We would find the odors of a Stone Age settlement most unpleasant. There were no soaps or deodorants, no flush toilets, or readily cleanable chamber pots, or any installations worthy of the term latrine. Wastes of various kinds were taken away to some customary distance and no further. Other wastes simply accumulated where they were produced. The average Stone Ager lived in a dump and moved away when conditions got really bad.

Children grew up, and adults lived out their lives, in the constant awareness, and sooner or later the personal experience, of woeful illness, painful injury, physical handicaps, debilitation, and death. There were no antibiotics, tetanus shots, or anesthetics, no plaster casts, corrective lenses, or prosthetic devices, no sterile surgery or false teeth. Our remote ancestors had few cavities, but they had many other dental problems. Teeth could be injured or lost in accidents, and they could literally wear out before what we call middle age. Abrasive plant products can wear molars down to gum level, as seen in some fossil skulls and even in some contemporary groups.

Lest it seem that our account of the EEA is merely a selection of items for a catalog of horrors, we should emphasize that we are discussing our fully human ancestors, with a fully human capacity for pleasure as well as pain and a fully human intellect. The bonds of kinship and friendship could be strong and a source of great pleasure and security. In seasons of plenty there would be abundant time for play: games, music and dancing, storytelling and poetry recitals, intellectual and theological disputes, and the creation of ornamental artwork. The cave paintings at Lascaux, France, created perhaps 25,000 years ago, have been described by anthropologist Melvin Konnor as "a Paleolithic Sistine Chapel" that impresses a sensitive observer "whether religious or not—whether expert or not—with a strong sense of the holy." And our ancestors also had the ability to look on the bright side in times of adversity and to find reasons for laughter. Mark Twain's hero Sir Boss in *A Connecticut Yankee in King Arthur's Court* lamented having to listen, at a sixth-century campfire, to the same jokes he had already found tiresome in the nineteenth. We suspect that if he had gone back to the Stone Age he would have groaned at many of the same jokes.

10

DISEASES OF CIVILIZATION

You have now spent several hours reading this book. Do you realize how much thoroughly abnormal use of your eyes this feat required? Was the light source the sun, with its normal spectrum? Probably not, at least not entirely. How much muscular exertion did you expend during those hours of reading? How could you be so inactive for that much time without jeopardizing your well-being, perhaps your life, by having spent inadequate time and effort in vigilance against enemies and in foraging for food? But you are in fact well fed? How long did it take to pick or dig or hunt or fish for your last meal? How much shelling and grinding and butchering? If the food was cooked, how long did it take you to gather the fuel and kindle the fire? How much sweating and shivering have you done in the last twenty-four hours? What's that about thermostatically controlled heating and air conditioning? How bizarre! And what are the long-term consequences of such meager challenge to your body's built-in temperature controls?

As the last chapter (we hope) made clear, only the grossly uninformed or irrationally romantic would think we were ever better off than we are now. Rousseau's noble savage and the Flintstones' merry capers are delightful in escapist fiction, but the reality was painful and sad compared to our lives today or even to when farming first replaced nomadic scrounging. Agriculture led to urban civilization, with its durable architecture and associated fine arts, and the nautical and other technological advances that permitted exploration of distant lands. The domestication of hoofed animals enabled one worker to do jobs that would previously have required several. It also contributed to revolutionary advances in transportation. Continuing technological advances have led to ever greater freedom from want and freedom of movement for ever larger numbers of people.

The long-term consequences of the soft and gratifying lives we now enjoy are mostly beneficial or harmless, but many of the advantages we enjoy today are mixed blessings. Benefits have costs, and even the most worthwhile benefits can be costly to our health. For a good example we need look no further than the effects of lower mortality rates in early life. Because fewer people die young from smallpox, appendicitis, childbirth complications, and hunting accidents, the death rates from old-age afflictions like cancer and heart failure are much higher now than they were a couple of generations ago. This is largely because a higher proportion of people live to the ages at which the body becomes especially vulnerable to these illnesses. The price of not being eaten by a lion at age ten or thirty may be a heart attack at eighty. Modern practices of food production, medicine, public health, and industrial and household safety have drastically improved the prospects of surviving to old age. Unfortunately, the increased effects of aging are not the only bad aspects of the good life.

Novel environments often interact with previously invisible genetic quirks to cause more variation in phenotypes, some of it outside the normal range. As described already in the chapter on genetics, these abnormalities arise only when a vulnerable genotype encounters an environmental novelty. Novel physical, chemical, biological, and social influences will cause problems for some people and not others or will have different effects on different individuals depending on their specific genetic makeup. We have already discussed some human examples; for instance, the genetic quirks that cause myopia impose problems in literate societies, but they caused no difficulties for our ancestors.

Our ways of getting food changed the environment in ways that created new problems. Thousands of years ago some of our ancestors hunted wild goats or cattle. Hunters followed herds for hours in the hope of killing one of the animals for food, hide, and other resources. Sometimes they may have found, early in the morning, the same herd they had been following the day before. If animals can be followed for two days, why not three, or a week, or a month? How long would this go on before the hunters would start thinking of the herd as their

own, driving off wolves or rival groups of hunters or other predators and chasing strays back into the group to maintain a large herd? This process gradually converted hunters into nomadic herdsmen.

Other ancestors were more vegetarian and found that some plants could produce a lot more food if they were intentionally planted for later harvest. Plowing, weeding, fertilizing, and selecting variants with the highest yields soon became standard practice and resulted in steadily greater and more reliable food production. It has been supposed that local increases in population may have encouraged the invention of agriculture or its adoption from neighboring peoples. Whether this is true or not, agriculture permitted the maintenance of much denser and more sedentary populations than could be supported by hunter-gatherer economies. Increased population density then became a source of other problems, some of which will be discussed in this, others in the next four chapters.

Modern Dietary Inadequacies

Paradoxically, the increased food production made possible by herding and agriculture resulted in nutritional shortages. There are more calories and protein in a bushel of wheat than in a handful of wild berries, but there is more vitamin C in the berries. If wheat provides most of the calories and protein for a farming community, deficiencies of vitamins and other trace nutrients are much more likely to arise than they would be with the more diversified diets of hunter-gatherers. If the wheat or other agricultural produce is also used as feed for the domestic animals that provide meat or eggs or milk, the farmers' meals are much improved, but shortages, especially of vitamin C, remain a threat.

Iceland is a good example, with a vitamin C problem that lasted well into this century. Icelandic farmers raised mainly sheep, which grazed the wild grasses of the countryside. The more successful families might have had a dairy cow, but mutton provided a large part of the diet, and wool was the chief commercial export, sold mostly to Danish colonials. The money so earned allowed the farmers to import flour and such luxuries as coffee and sugar. Nothing in the list so far contains vitamin C, which was provided mainly by blueberries and other wild plant foods. Unfortunately, the supply of these commodities was strictly seasonal. During winter and spring, when diets were notably lacking in vitamin C, many a seemingly robust and healthy Icelandic farmer would start bleeding from the gums and feeling lethargic and depressed, the usual symptoms of scurvy. Some members of a family would sicken and others not, with the severity of scurvy varying greatly.

For those who survived the winter sick with scurvy, folk wisdom came to the rescue. As soon as the marshes thawed, people could dig angelica roots, which are a fair source of vitamin C. The so-called "scurvy grass" might be sprouting at the same time and could be eaten as an alternative. The observation that such wild produce could cure scurvy antedated the use of citrus fruits for preventing the disease among long-distance sailors. Scurvy is a disease of civilization. Before people relied heavily on domestic plants and animals, they never had such abnormal diets as those of Icelandic farmers in the winter or sailors at sea for months at a time.

Long before there were any ocean voyages such as those of the original limeys or those that took the first settlers to Iceland, people suffered from other dietary deficiencies resulting from agriculture. About fifteen hundred years ago, some native tribes of the south central United States abandoned their hunter-gatherer lifestyles and started growing corn and beans. The change is clearly recorded in their skeletal remains. Compared with earlier skeletons, those of the farmers are on average less robust, and they often show effects of nutritional deficiencies of the B vitamins and perhaps protein. Despite these deficiencies, such farmers may have been less likely to die of starvation than their ancestors. They may even have been more fertile, because cornmeal and beans can facilitate earlier weaning. Nonetheless, in important respects, they were not as healthy.

These diseases of civilization thus existed fifteen hundred years ago in what would become Tennessee and Alabama, and long before that in earlier agricultural regions of other continents. The same sorts of nutritional deficiencies afflict the impoverished people of many third-world countries today. Our Stone Age ancestors no doubt faced frequent shortages of food, but if they were getting enough calories they were probably getting enough vitamins and other trace nutrients. Shortages of specific vitamins and minerals arose in just the past ten thousand years or so.

We are now aware of the need for vitamins and minerals, and we get more of them from a modern diversified diet than many early

agriculturalists did. Contrary to pharmaceutical sales pitches, few modern people need vitamin supplements. If we eat a diverse array of fruits and vegetables, some of them preferably uncooked, and especially if we also get abundant protein from grains, legumes, and animal products, we are getting all the vitamins, minerals, and other nutrients we need. The current danger for most of us is not the deprivation suffered by our ancestors but an excess of nutrition.

Modern Nutritional Excesses

A wise man once observed that it makes little sense to worry about excessive eating in the festive week from Christmas to New Year's Day. It makes much more sense to worry about what we eat between New Year's Day and Christmas. Of course, it is possible to overeat in a week. We can even overeat at one sitting, but this was also a danger in the Stone Age, and we are equipped with instincts to avoid doing so. There comes a point at which we feel stuffed and no longer hungry, even for that honey-cured Christmas ham. This normally puts an end to the meal and keeps us, as it did our ancestors, from overburdening the machinery of digestion, detoxification, and assimilation. Modern overnourishment is mainly the result of steady long-term overeating.

In the Stone Age it was adaptive to pick the sweetest fruit available. What happens when you take people with this adaptation and put them in a world full of marshmallows and chocolate eclairs? Many will choose these modern delicacies over an equally available peach, itself sweeter than any fruit available in the Stone Age. Marshmallows and chocolate eclairs exemplify the *supernormal stimuli* described by students of animal behavior. The classic example came from observations on geese. If an egg rolls out of a nest, a brooding goose will reach out and roll it back with her chin. Her adaptive programming is "If a conspicuously egglike object is nearby, I must roll it into the nest." What happens if you put both an egg and a tennis ball near her nest? She prefers the tennis ball. To her it looks more egglike than an egg. There can be supernormal stimuli in any sensory mode, for instance, taste. Next time you find yourself reaching for a slice of apple pie instead of an apple, think of that goose who seems to think she should incubate a tennis ball.

Our dietary problems arise from a mismatch between the tastes evolved for Stone Age conditions and their likely effects today. Fat, sugar, and salt were in short supply through nearly all of our evolutionary history. Almost everyone, most of the time, would have been better off with more of these substances, and it was consistently adaptive to want more and to try to get it. Today most of us can afford to eat more fat, sugar, and salt than is biologically adaptive, more than would ever have been available to our ancestors of a few thousand years ago. Figure 10-1 shows a plausible relationship between intake and benefit of these substances and proposes a contrast in the foraging capabilities of a Stone Age tribesman and of a high-salaried diner in a gourmet restaurant.

An overwhelming amount of preventable disease in modern societies results from the devastating effects of a high-fat diet. Strokes and heart attacks, the greatest causes of early death in some social groups, result from arteries clogged with atherosclerotic lesions.

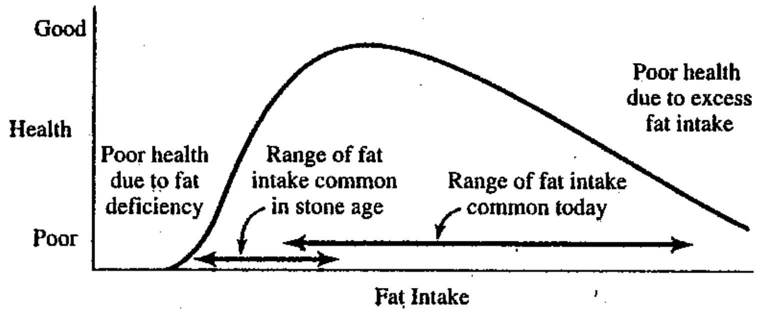

FIGURE 10–1.
Our view of the dependence of health and fitness on resource availability, such as dietary fat intake per month. We propose that fat availability in the Stone Age would seldom exceed the levels indicated. Today an originally adaptive craving for fatty foods may lead to intakes far out on the negative slope to the right.

Cancer rates are increased substantially by high-fat diets. Much diabetes results from the obesity caused by excess fat consumption. Forty percent of the calories in the average American diet come from fat, while the figure for the average hunter-gatherer is less than 20 percent. Some of our ancestors ate lots of meat, but the fat content of wild game is only about 15 percent. The single thing most people can do to most improve their health is to cut the fat content of their diets.

One of us once met with three others early one morning to travel to a hearing on claims that agricultural uses of pesticides were endangering the health of nearby suburban residents. A stop at a diner for breakfast yielded a vivid memory. One of the eaters lamented the likelihood that the wheat and eggs in his pancakes were no doubt contaminated with unnatural pesticides and antibiotics that might give him cancer ten or twenty years later. Perhaps so, but these toxins were a minor danger to his future health compared to the grossly unnatural fat content of his sausage and buttery pancakes, and the enormous caloric value of the syrup in which everything was bathed. The cumulative effect of that kind of eating is surely more likely to cause future health problems than are the traces of exotic chemicals.

Some people are more prone to this sort of overdosing than others. This is indicated by observable variation across the spectrum from underweight to overweight. Overweight people are more likely to suffer the cardiovascular problems associated with excess nutrition and to have higher rates of various cancers. This common impression is supported by recent studies. University of Michigan geneticist James Neel and his associates have noted that efforts to relieve the chronic malnutrition of the Pima Indians of Arizona inadvertently caused an epidemic of obesity and diabetes. He proposed that the affected individuals had what he called "thrifty genotypes," a genetically based ability to get and store food energy with unusual efficiency. With what seem like normal diets many Pimas steadily increase their stores of body fat. This could well be adaptive in a world that threatens frequent famine. Those who have built up copious fat stores might survive a prolonged food shortage while their less efficient associates perish. Thrifty genotypes are not adaptive in a world in which food shortages never occur. The most famine-adapted individuals may just get fatter and fatter until medical problems or other difficulties intervene.

Excess nourishment is not an easily corrected health hazard, and many common solutions may do more harm than good. Voluntary restrictions on food intake may be interpreted by the body's regulatory machinery as a food shortage. The result may be a resetting of the basal metabolism so that calories are used even more efficiently and further fat reserves are amassed. Another consequence of food restriction is intensified hunger, with consequent eating binges. Studies of artificial sweeteners fail to show that they help people to lose weight, a finding that might have been expected. Sweetness in the mouth, throughout human evolution, has reliably predicted sugar in the stomach and shortly thereafter in the bloodstream. It is not surprising that the sweet taste quickly resets metabolic processes so as to curtail the conversion of fat and carbohydrate reserves into blood sugar. This would be adaptive only if, in fact, the stomach contents quickly compensate for the change. If the sugar signal is a lie, there could soon be deficient blood sugar and increased hunger, especially for quick-energy sources like candy. There has been little recognition of such effects of artificial sweeteners. A similar hazard may be anticipated for nonnutritive fat substitutes. There are now desserts that look and taste like ice cream but are not only low in sugar but free of fat. What kind of signals do these send to the metabolic regulatory mechanisms?

Dental cavities are rare in preagricultural societies. If dental workers had been conscious of Stone Age fitness requirements, they would have realized long ago that the twentieth-century epidemic of dental caries must have been due to some environmental novelty, which we now know to be the frequent and prolonged exposure of the teeth to sugar. It nourishes bacteria on the teeth that generate acid, which in turn erodes the dental enamel. Here likewise there is prehistoric evidence for the harmful effects of dietary sugar. Skeletal remains more than a thousand years old from coastal areas in what is now Georgia (USA) show few dental cavities. They became common with the introduction of maize-based agriculture, and perhaps corn syrup, at about that time. They became still more common with the introduction of other forms of sugar by European settlers.

Cavities are technically not a nutritional problem, but they are a dietary problem and very much a disease of civilization. The good news is that they are of steadily decreasing concern. They were a serious scourge for adolescents and young adults born in the United States before 1940. Advances in preventive dentistry, such as fluoride treatment, have helped to overcome the difficulty, but before

these advances could be made it was crucial to realize that sugar is the culprit.

Simple rules and illustrative devices such as Figure 10-1 are always based on conceptual simplifications and all-else-equal assumptions. A diet that is too high in calories and fat for one person may be ideal for another. Much depends on age, size, sex, reproductive processes, genetic factors, and especially activity levels. Early subsistence farmers maintained what might be considered, from an evolutionary perspective, a normal activity level. Except for professional athletes, dancers, cowboys, and a few other groups, most people in modern industrial societies have abnormally low energy expenditures. Workers sitting in swivel chairs or in drivers' seats of cars or even pushing vacuum cleaners or electrically powered lawn mowers are being sedentary, and their leisure hours may be even more so.

During almost all of human evolution, it was adaptive to conserve energy by being as lazy as circumstances permitted. Energy was a vitally needed resource and could not be wasted. Today this take-it-easy adaptation may lead us to watch tennis on television when we would be better off playing it. This can only aggravate the effects of excess nutrition. The average office worker would be much more healthy if he or she spent the day digging clams or harvesting fruit in scattered tall trees. What would an ancestor of a few thousand years ago have thought of the expensive and complicated exercise machine in the office worker's basement—especially if it were actually used?

ADDICTIONS

Historical and anthropological records show that opium and other psychotropic drugs have been available throughout human history, with almost every inhabited region supplying one or more substances with the potential for abuse. Most addicting substances are elaborated by plants as a way of discouraging insect pests and grazers. Many act on the nervous system, and a few just happen to induce pleasure in humans. Alcohol is present in very ripe fruit, and storage of fruit juices yields a beverage with an alcohol content of up to several percent.

Substance abuse today is a greater problem than it was in preindustrial societies because of the technological innovations of the past few centuries or millennia. When every household had to make its own wine or other fermented beverage in small vessels and with primitive equipment, it was unlikely that anyone would have enough for heavy daily consumption. Urban civilizations, with their professional vintners and brewers, were more likely to provide the quantities of alcoholic beverages that would permit the wealthier classes to get all they wanted. Improved methods of storage and transportation, which allowed British tribesmen to get drunk on Roman wines, were another factor in the advance of alcoholism.

Another contribution to this advance was the invention of distillation. The readily available beverages containing a few percent alcohol could then be distilled into ones with high alcohol concentration. It may be easier to succumb to alcoholism by drinking gin than by drinking wine or beer. More recent innovations facilitated the production of heroin from opium and crack from cocaine, concentrates that are more rapidly addictive than the natural substances. The invention of hypodermic syringes is part of the same story. Similarly, the mass production of cigarettes from newly developed tobaccos that caused relatively little throat irritation greatly increased the incidence of nicotine addiction. Despite the great antiquity of addictive possibilities, the modern scourge of substance abuse is largely a product of our abnormal environment.

Of course, as every reader of the headlines knows, addiction is an inherited disorder. We are not sure what the average writer or reader of headlines might understand by this, but what we understand is what we discussed in Chapter 7 as genetic quirks. Some people can have frequent evening cocktails, wine or beer with meals, and occasional weekend binges and never show a sign of alcohol addiction. A person with the relevant genetic quirk will, with the same alcohol intake, show a steady increase in drinking until he or she is spending prodigiously to support an ever-worsening addiction and is ever less able to work and maintain normal social relationships. The consequences of this genetic quirk would have been minimal until after such civilizing inventions as stills and six-packs. Alcoholism and much other substance abuse can justifiably be considered diseases of civilization.

Developmental Problems from Modern Environments

Lack of adequate exercise may be expected to cause problems other than those associated with overweight and fatty foods. It makes no evolutionary sense, for example, for the human developmental process to cause a large proportion of the population to grow incisors in malfunctional positions and to suffer so many problems with wisdom teeth. If a large proportion of modern children need orthodontia and then later some require expensive and painful surgery on wisdom teeth, it implies that there is something wrong with their environment.

One possibility is a deficient demand for jaw exercise. No Stone Age ten-year-old would have been living on foods of anything like the tenderness and fragility of modern potato chips, hamburgers, and pasta. Their meals would have required far more prolonged and vigorous chewing than is ever demanded of a modern child. We wonder if deficient use of jaw muscles in the early years of life may result in their underdevelopment and indirectly in weaker and smaller associated bone structure. The growth of human teeth is more autonomous, but it assumes a jaw structure of a certain size and shape, one that might not be produced if usage during development is inadequate. Crowded and misplaced incisors and imperfectly erupted wisdom teeth may be diseases of civilization. Perhaps many dental problems would be prevented if prolonged vigorous biting were considered a prestigious athletic attainment for children. Perhaps chewing gum should be encouraged in schools!

Other abnormal behaviors during childhood might cause abnormal physical development. Sitting for hours at a time on chairs or benches in classrooms is unnatural, and nothing of the sort was ever demanded of Stone Age children. When they were sedentary, they would have been squatting, not sitting. Stone Agers must also have been able to shift from squatting to kneeling to walking or running or other sorts of activity. Might it not be that many of today's sufferers from lower back pain owe their distress to the hours of abnormal posture imposed day after day during childhood? Maybe the later problems could be avoided by having children do more squatting and less sitting and giving them more exercise breaks or walks between classes.

University of Michigan physician Alan Weder and his colleague Nicholas Schork have tried to understand high blood pressure as a disease of civilization. Instead of emphasizing the high levels of salt in our diets, however, they note that blood pressure must be higher to supply the needs of larger bodies and that there is a mechanism that increases the pressure during adolescent growth spurts. In the ancestral environment, they argue, this mechanism would have made adjustments within a range of small body sizes. Today, our nutritionally rich environment yields fast growth and large body sizes that were rare in the past. The blood-pressure-regulating mechanism, pushed to adjust the system outside the range for which it was designed, often overshoots, causing high blood pressure.

Myopia is not the only ocular abnormality that may arise from novel environmental conditions early in life. Medical science has only recently become aware of ways in which eye usage in the first weeks and months after birth may be critical to the normal development of vision. Preferential use of one eye rather than the other, from whatever cause, may lead to changes in the allocation of brain regions to ocular functions so that a child may later prove incapable of using binocular cues for depth perception. Twenty-four-hour bright lights, sometimes used to treat neonatal jaundice, can cause color-vision defects not likely to be detected until much later. Would it be surprising to discover that constant exposure to loud noises, especially the unchanging sounds of modern machinery, can cause defective hearing development in some babies?

Other Diseases Resulting from Modern Environments

Cold weather can be considered a novel environmental factor. The spread of human populations to seasonally cold environments was facilitated by technological innovations, such as clothing and fire, which we achieved only a few tens of thousands of years ago. We still need these artificialities, or their modern equivalents, to survive the winter over much of the

currently inhabited surface of the earth. Technology compensates for human biological inadequacies in dealing with such novel environmental threats as frostbite and hypothermia.

But low temperature is not the only stress imposed by high latitudes. Clothing and shelter that enable us to survive in places like Montreal and Moscow impose their own health problems. Our synthesis of vitamin D depends on our exposing our skins to sunlight. If we are indoors much of each day and largely covered with clothes when we are out, the amount of vitamin D we synthesize will be a tiny fraction of that made by a naked forager on the African savannah, and it could be grossly inadequate for our metabolic needs. Fortunately, our photosynthetic capability is not our only source of this material. We can also fulfill our vitamin needs by eating certain foods. Unfortunately, a seemingly adequate diet may in fact provide very little vitamin D, and a deficiency leads to health problems related mainly to abnormalities of calcium metabolism.

The most commonly recognized effect of vitamin D deficiency is rickets, a developmental disease of childhood. The symptoms are many, but the most important is defective growth of the bones. They become soft and weak from deficient calcium deposition and grow abnormally. The disease is essentially unknown in the tropics, where everyone gets abundant sunshine, and uncommon in Japan, Scandinavia, and other regions where traditional diets include good sources of vitamin D, such as fish. But at times it affected such large numbers of children in England that it was sometimes called the English disease.

Rickets was also a frequent malady in northern American cities prior to the 1930s, when vitamin D began to be routinely added to milk. Rickets struck black children at a higher rate than white. The adaptive significance of human racial differences is generally dubious, but the reduced vulnerability of pale-skinned people to rickets may be a valid example. Perhaps the first people who crossed the Mediterranean and later the Alps were quite dark. They found a land covered with trees under a sky often covered with clouds. During much of the year they spent long hours huddling in caves or drafty shelters. When they went outdoors they clothed themselves with animal skins or woven fabrics and exposed very little skin to the meager sunshine. The result, for many people, may have been depressed fitness because of vitamin D deficiency. Those who happened to have less heavily pigmented skins, which admitted more light for vitamin D synthesis, would have fared better than their darker neighbors.

In this way light skin may have evolved in perhaps a few hundred generations. The change may have been rapid because reductions of a trait are generally easier to evolve than increases or elaborations. Cave animals may lose almost all ability to make pigment in a few thousand generations, and this happens merely from relaxed selection for the maintenance of color. If there is an actual advantage to paler skin, the change should be much faster. The same evolutionary reduction of melanin synthesis may have happened, though to a lesser extent, in the colder parts of Asia, where forests give way to grasslands and deserts and winter days are more often sunny. The native peoples of Siberia and northern China are darker than those of central and northern Europe but paler than those of Africa or southern Asia. As a disease of civilization, rickets is more of a hazard for people with highly pigmented skin, and pale skin may be recognized as especially adapted to a scarcity of sunshine. But then what happens when these pale people move back to sunny regions, such as Australia? Stay tuned for more on the sunshine problem (Chapter 12), and recall our discussion of sunburn in Chapter 5.

As noted above, the invention of agriculture led to population densities much greater than could be achieved by hunter-gatherer economies, and it permitted the support of great concentrations of people in cities. The spread of people into seasonally cold environments led to their prolonged concentration inside caves and buildings. Both these changes increased the number of people a given individual would contact in a short period of time and increased the closeness and duration of such contacts. New infectious diseases could then emerge that could be spread only by abundant personal contact.

Much of the natural selection taking place in these populations may have consisted of the weeding out of individuals whose genetic quirks made them vulnerable to smallpox, measles, or other contact-transmitted diseases. High-cost defenses against such tropical diseases as malaria, for example the sickle-cell trait, would have been lost rapidly. The effectiveness of the newly evolved defenses against such diseases as smallpox was tragically shown when settlers, carrying what for them were well-controlled pathogens, invaded parts of the world where native peoples had never been exposed to the diseases of civilization. Far more New World people were killed by European diseases such as smallpox and influenza than by European weapons.

In this chapter we have scarcely hinted at the many psychological problems that may arise from modern life. Despite the family-values rhetoric of politicians, children raised by nuclear families in single-unit suburban dwellings are experiencing a profoundly novel social environment, as are those being supervised by transient caretakers in day care centers. As adults and even as adolescents and children, we may have to deal more often with impersonal bureaucracies than with familiar individuals. Most of the people we encounter on what seems to be a normal day may be strangers. This was not the kind of world our ancestors evolved in. What about the prolonged winter darkness of high latitudes and, conversely, the hours of bright indoor lighting and resulting shortened periods of real darkness we actually experience? The cabin fever of snowbound Alaskan gold seekers is now a recognized malady that is getting attention from medical researchers. What about night-shift workers and the jet-lagged jet set? And then there are the psychological—as well as physiological—effects of offices without windows. We have just begun to explore the medical consequences of our novel modern environment.

Conclusions and Recommendations

There is no Eden we can go back to even if such a move were desirable. What we can do is be alert to the modern dangers and take reasonable steps to forestall them. As with many other topics discussed in this book, our main recommendation for anyone faced with a problem of medical importance is to consider the question: What is its evolutionary significance? One possibility is that it is an adaptive mechanism, but this will normally mean adaptive in the Stone Age. Our cravings for sugar and fat, our tendencies to be lazy, and our eye-growth adjustments that result in myopia are evolved adaptations, but in modern environments they cause difficulties for many people. Other evolved attributes, such as senescence and susceptibility to sunburn, are adaptive in no environment but may represent costs of other adaptations. Again and again we harp on the themes that all benefits have costs and that many benefits are worth their associated costs.