O woe! What do I do now, where do I go now?
Death has devoured my body,
Death dwells in my body,
Wherever I go, wherever I look, there stands Death!

Gilgamesh (Tablet 11)

Preface

I plan to live forever. My entire career has centered on that singular goal: defeat aging and live forever.

Ever since I was very young, and I was told that one day I would grow old and die, I've devoted practically every waking moment of my life to trying to prevent that from happening. And why not? If you learned that there was an enemy that was going to kill you and your friends and your family and everyone else on the planet, wouldn't you spend your time and energy figuring out how to stop it? It's always seemed obvious that aging is that enemy.

That's why I've always made it my personal motto to "cure aging or die trying." Sure, the motto is meant to be amusing, because it's both the familiar "or die trying" cliché and also a tautology—which is to say that, obviously, anyone who doesn't live to see a cure for aging won't live at all. But I guess that's what makes the joke seem so deadly serious to me.

Aging is a complex and difficult topic, especially when you declare, as I do in this book, that it's a treatable, if not outright curable, condition. At the risk of inviting suspicion, this book is my declaration that human aging can be controlled and stopped. This is not nearly as radical a statement as some might think, nor is it a statement that relies on a presumptive belief in its truth. It is not pseudo-science. It is not quackery. It is a statement solidly

grounded in good science, which makes it both verifiable and demonstrable.

Some readers might have taken note here that I referred to aging a "condition" rather than a "disease." That may seem like a pointless semantic distinction. Actually, as far as I'm concerned, it *is* a pointless semantic distinction. Is aging itself a disease, or is aging simply responsible for the dozens of diseases associated with aging? To me, it doesn't matter. Cure the condition, and you cure the diseases. But there are vast legal implications in that word choice. The government gives grant money to cure diseases, but not to cure conditions. Dietary supplements can legally be sold to treat conditions, but not to treat diseases.

As I will discuss in much greater detail later, it's been known for decades that much of the puzzle of aging relates to the telomere, the repetitive region of DNA at the end of our chromosomes. Without these telomeres, our cells cannot divide, and it's the progressive shortening of our telomeres throughout our lives that leads to most or even all the diseases of aging—cancer, atherosclerosis, and osteoporosis, among many others.

I've spent decades keeping current with the scientific research on the association between telomere shortening and the diseases of aging, and it is clear that what we think of as "aging" is not dozens of independent diseases. We're looking at exactly one underlying problem. If you're uncomfortable calling that disease "aging," you can refer to it as Telomere Shortening Disease or Short Telomere Disease. Again, it's just a matter of semantics. The disease that makes our bodies degenerate and wither away is what I intend to cure.

Defeating aging is the first step in the much broader goal of clinical immortality: assuring that no one will ever die unless by their own choice. Some of the harsher critics of clinical immortality have charged that it's a goal that's inherently selfish. They talk about a duty to die and make room for the next generation.

A “duty to die”? That’s an idea that’s always puzzled me. After all, our culture recognizes both a right and a duty to live. In fact, it’s one of our most fundamental beliefs. We frown upon habits that would shorten our lives, like tobacco smoking and sedentary lifestyles. And the concept of suicide horrifies us so much that it’s a crime to even attempt it. The idea of duty to live is so important to us that many do not even acknowledge a right to die... that is, until we’re in our eighth or ninth decade of life.

But at that point, we are expected to decline into a helpless, degraded state, where we’re unable to care for ourselves, where we have no choice but to force society to pay millions of dollars for our care and put our loved ones through the anguish of watching us deteriorate before their eyes. And this expectation takes on moral undertones, almost as though we have a *duty* to put ourselves and our families through this suffering.

Where’s the moral sense in that? But, I’m a scientist, not a philosopher, and certainly not a theologian. Although I was raised Catholic, I’ve considered myself an agnostic for almost as long as I can remember. In my view, there are certain questions the scientific method can answer, and certain questions it can’t. The questions that it can answer, we should aggressively explore. As for the questions that it can’t, perhaps all we can do is wait and see whether we ever learn the answers.

The foremost question in my mind has always been *why* we don’t live forever, not whether we should. It’s an interesting question, and any answer is going to be somewhat speculative, but the scientific explanation is the one that makes sense to me.

I. Why Do We Age?

Throughout the history of science and technology, there are plenty of examples of problems being solved before they are even fully understood. The Wright Brothers, for example, had only a very basic understanding of the principles of aerodynamics. They designed technology to outrun the science of the day, putting together a machine where even though it eventually worked, they could not exactly explain why. However, they were successful and achieved their goal of heavier-than-air flight, which led to a revolution in transportation. Eventually, I hope to repeat the same feat when it comes to human aging, designing a drug that works even if the internal mechanisms that make it work have not been thoroughly described.

But we cannot entirely count on the idea that technology can always outrun scientific understanding. Understanding the nature of a problem is often necessary to solving it. And that’s why I’ve given so much thought to the question: “why do we age?”

It’s an ambiguous question in many ways. People are not always asking the same thing when they ask that question. Some people want to know why human beings have an aging process. Why are we afflicted with it? What is its purpose? And some are asking for the nuts and bolts: “How does the human aging process work?” I’ll get to both of those soon enough, but let’s tackle the first question first.

Why do human beings have an aging process?

Asking why humans have an aging process sounds like philosophical musing. But, in reality, the question is fundamentally one of biology, and a very important one. After all, my life goal is to control the aging mechanism—speaking metaphorically, I want to isolate and remove that feature of the body. If an engineer comes across a device and wants to remove a superfluous component, it’s very important to first ask: what does that component *do*?

I consider that a suitable metaphor for the aging question. The device is the human body. The component we don’t like is the fact that people die in less than 125 agonizingly short years. So, we should remove it. People ask, "Are you sure that's safe? Are you sure that aging isn't a critical part of us? Are you sure that the whole human body—or even the whole human species—won't break down without it?"

Those are very valid questions. After years of research, science is beginning to discover just what the aging process is. And the more that we learn, the more all the evidence points to the conclusion: yes, aging is something we can and should eliminate.

Before I tell you what aging *is*, let me tell you what aging is probably not. There are many theories of aging, and I don't want to rule any of them out, because my ultimate goal is to live forever, and I'd hate to fail to make progress because I was too married to one theory.

The way I explain it is this: I think of all the causes of aging—the ones I believe in as well as the ones I'm very skeptical about—as sticks of dynamite inside the body. Which one do we need to defuse first? The one with the shortest fuse. For example, I have little doubt that advanced glycation end-products and cross-linking play a role in human aging, but they are not the problem that needs to be addressed first.

Below are some more general theories of aging that I deprioritize; I tend to think of as having longer fuses.

Aging is not an inevitable breakdown of order.

It's a common school of thought that everything ages. Even a mountain eventually erodes and crumbles and ceases to exist. Sometimes this school of thought is purely philosophical; sometimes it references the Second Law of Thermodynamics. But ultimately, it argues that time causes any and all order to slowly break down, and therefore, everything must age.

But there's one important exception that this theory doesn't take into account: things don't get older with constant maintenance. Most cars

last about 100,000 miles over less than 10 years before they become too expensive to maintain and are discarded. We could say that this is the typical "lifespan" of the car. But, of course, with regular maintenance, the lifespan could be increased. You can replace every part as it goes bad, and cars can continue to function after fifty years, after a million miles. There's no theoretical limit: If you're willing and have the means to maintain a car forever, it will last forever. That's no more apparent anywhere than in my home of Reno, Nevada, where every August we have the country's largest classic car festival, where the streets are full of cars as old as I am, manufactured in the 1950s, yet looking like they just rolled off the assembly line.

Of course, most people replace their cars rather than maintain them forever. They are not concerned with keeping one car; they only need a functioning vehicle. We cannot discard a withered and aged body for a new one, so we must maintain the one we have, addressing the damage that our bodies are incapable of repairing on their own.

(At least, we can't make that trade just yet. There are promising technologies in the early stages of research and development, like nanotechnology or digital consciousness, that suggest this may one day be possible. I do like to spend some time thinking about these theoretical future technologies, although my focus in my career has always been to tackle the problems I think can be solved within my lifetime.)

For now, we have one body, and we're stuck with it. The good news is that there's no reason it can't run forever with constant maintenance. My mission, one that has seen remarkable strides in the past eighteen years, is to convince our bodies to perform that maintenance. Our bodies are built to maintain themselves to an extent through cell division, but our cells are specifically programmed not to divide indefinitely. And this is the heart of the aging problem, and the central focus of this book.

I have occasionally heard people object that a cure for aging is a violation of the Second Law of Thermodynamics, which predicts a progressive decrease in order in any system. But life does not seek entropy in the short term. A chunk of sandstone and granite will eventually disorganize and crumble to dust – unless a seed takes root in it. Then, the atoms of that same chunk of rock will find themselves becoming more organized, not less. They organize first into a plant, and then, as that plant is eaten and metabolized, into the energy to perform a willful action. Unless we're going to worry prematurely about the heat death of the universe, we probably don't need to view entropy itself as an obstacle to an aging cure.

Aging is not a slow buildup of environmental damage.

For centuries, probably the most prevailing theory about aging has been that it's basically a "wear and tear" phenomenon—that a person ages in essentially the same way a car does. Even the most prominent scientists and experts believed that we're born undamaged, and that every day we're on earth, we accumulate damage. We breathe in toxins, we're scorched by the sun, every step we take puts strain on our bones and muscles, and eventually we break down. We're born with brand new parts (in our case, muscles and bones and organs), and over time, we wear them out.

But this theory does not explain the entire aging process. If it were the sole basis for aging, we'd see far more variability in people's ages. The more "wear," the theory would suggest, the more "tear." In other words, people who lived active lives would look older than people who spent most of their time sheltered and inactive.

If you leave a car sitting in a garage with its gas tank empty and its battery disconnected, it is practically "immortal" by car standards. If you drive it a hundred miles a day, it wears out comparatively quickly. Yet somehow, the *opposite* is true of human beings.

Some humans almost seem to be attempting to preserve themselves the same way as the car: there are people who spend the majority of their lives lying on a couch in a 70 degree temperature-controlled room, watching television. If the "slow buildup of damage" theory explained aging, we'd expect these people to live ten, twenty, fifty times as long as people who run marathons.

But of course it's the opposite. Keeping a car in motion shortens its lifespan, but keeping a human in motion lengthens our lifespan. So how could a "wear and tear" theory possibly be true?

Many other attempts to explain the biological mechanisms of aging essentially came right back to the "wear and tear" theory: that we aged due to accumulated damage from the sun, or that we aged due to free radicals from our own metabolism. But in each case, there wasn't enough variability among people of the same age to justify the theory. People living at the equator age at about the same rate as those living at the poles. People with radically different diets have only slightly different life expectancies. Except in the most exceptional circumstances, you can look at a person and guess their age to a few years.

And then there was the problem of animal lifespans. Why do mice have one lifespan, and cats have another, and humans yet another, when we're all affected by the same environment? To this day, I'm sometimes asked questions like "Could the extreme longevity of sea tortoises be related to their cold environment and constant exercise?" And I have to point out that many species of fish that live only three or four years share the same environment and essentially the same "lifestyle." So, whatever they're dying of, it's not a consistent or measurable accumulation of environmental damage.

Aging is not our way of keeping the population in check.

There are people who think aging must be nature's way of keeping the human population down. And to some extent that's an intuitive conclusion: it makes sense that if we have a way to get rid of individuals in the population, we won't ever end up with more people than our environment can support. That aging is an escape valve against overpopulation.

The problem with that theory is that aging is objectively terrible at that "escape valve" function. If aging were our only mechanism to keep the population in check, we'd have overrun the Earth long ago.

A few hundred years ago, before medicine and science had begun to address lower infant mortality rates, it was unusual to die of aging. People died of diseases, wars, natural disasters, epidemics, childbirth. Aging was never the mechanism of population control. And despite those hardships, human populations swelled and thrived all across the world.

It's mathematically refutable that aging can keep our population level in check. Let's say, hypothetically, that a ship of a thousand colonists landed on a distant planet, one without disease or predators, and they wanted to populate that planet as quickly as possible. So, upon turning 20 years old, each person would get married and have six children, one after another—a fairly typical family size in pre-industrial society, and one we'd be likely to return to on a pristine planet. In just 80 years—4 generations—that thousand people would have turned into seven thousand, then into 43,000, then into 259,000, then into 1,555,000.

In other words, in just one lifetime, humans have the reproductive capacity to multiply themselves by more than a factor of a thousand. So, by the time the population of the planet reached a million, fewer than a thousand people would have died of old age. And by the time those million people died of old age, there would be a billion new people to replace them. This vastly exceeds any "escape valve" effect that aging can provide.

The philosopher Thomas Malthus certainly knew that aging was no hedge against population growth. Malthus is best known for his theory that human population growth was a force that could not be stopped. He thought the population would continuously grow until there was no more food, water, or shelter, and that the destruction of humanity was inevitable, because we would simply overrun our environment until everything was gone, and then we'd lie down and starve to death. Malthus never factored in an aging process: to him, the numbers made it very clear that we could overpopulate ourselves to death without any aging process at all.

What Malthus probably did expect is that we'd have already bred ourselves into extinction by the present day. Obviously, his theory hasn't held up. It turns out that our species, like most, is biologically programmed to seek a stable population level. With humans, this programming manifests itself in our economics: as the price of buying a house and raising a child rises, people naturally postpone children, or even swear off having them entirely. And, in the most developed parts of the world, population growth is approaching zero, or even has hit zero and is now slightly negative.

The citizens of Japan, for example, on their small, comparatively resource-poor islands, are not stripping the land bare like a plague of locusts. The population growth in Japan (as of 2010) is -0.1%. It should go without saying, but this isn't because the Japanese are aging faster. It isn't because the "escape valve" of aging is functioning better. In fact, the Japanese are some of the longest-lived people on Earth. Rather, it's because the Japanese have stopped having children at more than a replacement rate. There is something innate in all of us capable of making us think "It is too crowded and too expensive to have a child right now" when we are faced with overpopulation. That's the actual mechanism that keeps our population in check, not our aging process.

The bottom line here is: a population without aging, or even an immortal population, will probably develop a nearly childless culture. Not because of radical laws, but because it is just our natural biological inclination to do so.

Aging is not an inherent feature of life.

A common misconception exists that all living things age. It is not true.

All living things eventually die, yes, but aging is not the same as mortality. A biological definition of "aging" is that an organism's mortality rate increases over time. For example, ten year old dogs have higher mortality rates than two year old dogs: therefore, it can be said that dogs age.

This is not true of bacteria. Many bacteria have very high mortality rates, but there is no relationship between that mortality rate and time. A two day old bacterium is no more or less likely to die than a twenty day old bacterium; it will die when something kills it. Therefore, bacteria can be said to have no aging process.

There are actually quite a few species that do not age. One that has been getting a lot of press lately is *Turritopsis nutricula*, or the "immortal jellyfish." This organism can revert to its polyp stage after reaching sexual maturity; there is no theoretical limit to the number of times it can go through these cycles of maturation and reversion.

No one suggests that humans should (or could) mimic this strategy of repeatedly going through infancy, but there are also animals that employ no such strategy, but simply do not have an aging process. One of the most notable is lobsters. Lobsters do not experience rising mortality rates with time. The only way to estimate a lobster's age is by weighing it, since they grow throughout their lifetimes. The largest lobster ever captured weighed over 20 pounds, and its age was estimated at 140 years.

It is also unknown whether tortoises have an aging process. There is no concrete evidence that they have a theoretical maximum lifespan or that their mortality rate rises with age. A tortoise personally collected by Charles Darwin only recently died, at the age of 175. The oldest tortoise alive today, who lives on the island of Saint Helena, is believed to be over 180 years old.

Aging is not the body's defense against cancer.

You may have heard about the recent school of scientific thought that aging is a mechanism to ensure that we don't develop lethal cancers early in life. In my opinion, this hypothesis has been thoroughly discredited. If anything, aging is a primary cause of cancer, not a preventative measure against it! But I'll discuss this in more detail later in this book.

So if aging is not any of these things, what is aging?

If you'll allow me to make a metaphor that's a little strange, I believe that aging is a bit like a leftover stockpile of nuclear weapons from a war that ended centuries ago.

The history of life on Earth is a long story of what could be characterized as a kind of biological warfare. The predator tries to catch the prey; the prey tries to escape the predator. And both of them need to constantly refine their ability to do those things. If the balance shifts too far in one direction – if the predator becomes too efficient at catching the prey, or the prey becomes too efficient at eluding the predator – then one species faces extinction. In fact, both species may face extinction, as the food chain collapses: predators don't last long without their prey.

So, to ensure survival, every species must constantly adapt. If a lion becomes faster, its prey must develop new defenses, such as camouflage, or defensive weapons like horns, or armor plating like a turtle's shell. And then the lion must evolve ways to overcome those defenses, lest it starve.

With this in mind, it becomes easy to see why a lion needs an aging process. If lions were immortal, their prey would be evolving—and they would not. Over thousands of years, the lion's prey would become harder and harder to catch. Eventually, it would become impossible, and that lion, along with its entire species, would starve. Paradoxically, long-lived individuals would guarantee a short-lived species. And the genes for immortality would die off with the species.

Lions are apex predators; they sit at the top of the food chain. Other animals at the top of the food chain are dogs, cats, and humans, so all three need an aging process. And indeed, studies have shown that dogs and cats age in much the same way that humans do: through telomere shortening.

You might be thinking: but why does the lion's *prey* need an aging process? After all, even if a gazelle didn't age, it would presumably be killed by a predator eventually, meaning it would be replaced by its offspring, and natural selection could continue. Obviously, it isn't mortal out of some genetic sympathy for the lion!

The real problem is that without an aging process, it's unlikely that the gazelle *would* be replaced by its offspring. More likely, it would replace its own offspring! There is no evolutionary advantage to living longer than it takes to raise our young. In fact, there is a disadvantage.

An immortal gazelle would most likely out-compete its offspring and prevent them from being able to survive. Individuals of every species compete with each other for resources—for food, for mates, for shelter, etc. And the longer a young, healthy animal survives, the more experienced it becomes, and where applicable, the more resources it acquires and the more it solidifies its social position. In order for a young gazelle to have any hope of competing with a mature one, nature must make the mature one step aside. And it does this by making the mature one weaker, frailer, more prone to disease. In other words, by making it age.

Following this line of reasoning, it starts to become very clear what aging is. Aging isn't an accident; it isn't an inevitability; it's very specifically programmed into our bodies as a survival advantage against other species that would compete with us. It's a tool that has allowed us as a species to survive for millions of years and become what we are today.

Humanity no longer needs this tool. We aren't locked in a daily struggle for survival against Mother Nature anymore. We grow, raise, breed, and even genetically engineer our own food. Our crops are not going to become inedible because of a failure to continue to evolve the ability to digest them. Our livestock aren't going to spontaneously learn how to defend themselves from us. And nothing that would ever try to prey on us has any defense against the weapons we can build.

Humans are the first species on earth that have developed brains powerful enough to take control over our environments – which means that we are winning the eons-old biological war. We have taken control of evolution itself: we domesticate both plants and animals into forms more favorable to us. We create tools that serve as "workarounds" for our physical shortcomings, from eyeglasses to footwear to vaccines. In all the eons of biological warfare on Earth, ours is the first moment of relative peacetime.

And that's why I think of aging as a "leftover stockpile of nuclear weapons." The war is long over, and the weapons are doing us no good. They're expensive to maintain. And as the radiation leaches out of them, they're slowly killing each and every one of us.

In the past, aging was a powerful weapon, but now it's safe to disarm it – and anyone who doesn't want to die a needless and debilitating death should be interested in learning how to do so. To do that we need to know how the aging process works.