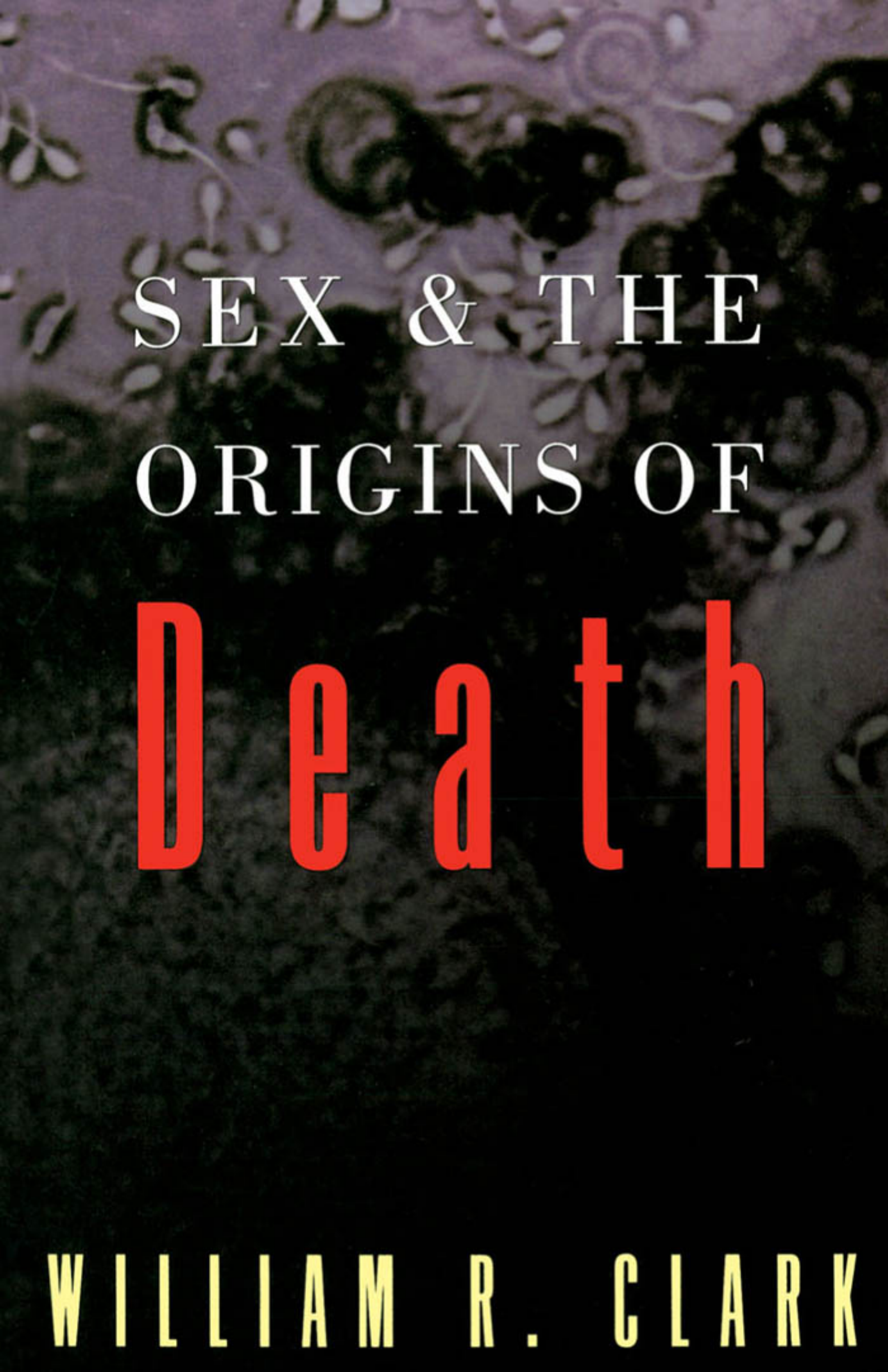
SEX & THE
ORIGINS OF
Death
WILLIAM R. CLARK

Sex and the Origins of Death

This page intentionally left blank

Sex and the Origins of Death

William R. Clark

OXFORD UNIVERSITY PRESS

New York   Oxford

Oxford University Press

Oxford New York
Athens Auckland Bangkok Bogotá Bombay
Buenos Aires Calcutta Cape Town Dar es Salaam
Delhi Florence Hong Kong Istanbul Karachi
Kuala Lumpur Madras Madrid Melbourne
Mexico City Nairobi Paris Singapore
Taipei Tokyo Toronto Warsaw

and associated companies in
Berlin Ibadan

Illustrations by Celine Park

First published by Oxford University Press, Inc., 1996

First issued as an Oxford University Press paperback, 1998

Library of Congress Cataloging-in-Publication Data
Clark, William R., 1938–
Sex and the origins of death / by William R. Clark.
p. cm. ISBN 0-19-510644-X
ISBN 0-19-512119-8 (Pbk.)
1. Cell death. 2. Death (Biology) 3. Apoptosis. 4. Sex (Biology) I. Title.
QH671.C56 1996
574.87'65—dc20 96-11753

10 9 8 7 6 5 4 3 2

Printed in the United States of America

Acknowledgments

A number of people have worked hard to help me in various stages of creating this book. At Oxford University Press I have enjoyed the continued encouragement and support of Kirk Jensen and Laura Brown. I am especially indebted to Joy Johannson, whose mastery of literary English has been an inspiration and a guide. She pushed me to make this a much better work than it might otherwise have been, and greatly increased my pleasure in what I have written. In this as in previous works I have found the advice of my good friend and fellow scientist Robert Eisenstein of immeasurable value.

This page intentionally left blank

Contents

Prologue, ix

1. Death of a Cell, 3
2. A Second Face of Death, 27
3. Sex, Segregation, and the Origins of Cellular Death, 53
4. From Sex to Death: The Puzzle of Senescence, 79
5. A Hierarchy of Cells: The Definition of Brain Death, 105
6. Standing at the Abyss: Viruses, Spores and the Meaning of Life, 135
7. Coming to Closure, 159

Epilogue, 171
Further Reading, 181
Index, 187

This page intentionally left blank

Prologue

As promised so clearly and unapologetically in the book of Genesis, knowledge carries with it a terrible burden. Human beings, uniquely among all living creatures on this earth, know that one day they will die. It is a painful knowledge. We have spent most of our history as a knowing species devising belief systems that help us either accept or deny that single fact. No human culture ignores it. It colors our experience as individuals, and often influences our collective actions. Death is a subject that simultaneously terrifies us and fascinates us. Understanding that terror and fascination is an important part of human psychology.

While we continue to think about death from philosophical, cultural or religious points of view, we also study it scientifically. Thanatology, the study of death and dying, is a recognized branch of medicine, with its own scientific journals. But thanatology focuses on the psychosocial aspects of death and dying; it does not ask questions about the nature of death itself. The branch of medicine called pathology describes in great detail the changes in the body and its cells and tissues that lead to or accompany disease and death. A pathologist can tell us whether a tissue is healthy or diseased, alive or dead. But about the precise nature of the razor-thin line separating life from death, the pathologist has little to say.

So *what is death*? One way to understand the death of a human being is to seek the smallest, ultimately indivisible unit — the "atom" of the ancient Greeks — of human life. That unit, that atom of life, is the cell. The cell is the smallest unit in the human body of which we can say, "This is alive!" And if we can define cells as having life, then it follows that it must be possible to describe them in the absence of life — when they are dead. What does a dead cell look like? What is it missing? Why is it dead? How did it make the transition from alive to dead? *How did it die*?

These are important questions, because the death of every human being begins with the death of just a few cells. We normally think of death in terms of *death of the person* — the integrated whole composed of personality, will, memory, passion, and the hundreds of other things that make each of us unique. Most of these characteristics are housed in a specific portion of the brain — the cortex — and the loss of "personhood" that results from loss of cortical function is increasingly viewed as one of the most important aspects of human death. But clearly death must also have a biological meaning independent of the human condition. In the death of our cells, we are no different from all of the other organisms on earth condemned to die as a condition of birth. Snails die, as do worms and mushrooms, and their deaths too begin with the death of just a few cells.

The study of death at the level of individual cells has revealed unexpected subtleties and complexities about the nature of death in multicellular creatures like ourselves — for example, the widespread occurrence of suicide among cells in our bodies. Surprisingly, the study of evolutionarily older single-cell organisms suggests that cell aging and death is *not* an obligatory attribute of life on earth. Obligatory death as a result of *senescence* — natural aging — may not have come into existence for more than a billion years after life first appeared. This form of *programmed death* seems to have arisen at about the same time that cells began experimenting with sex in connection with reproduction. It may have been the ultimate loss of innocence.

Trying to grasp the meaning of an infinite and ever-expanding universe has led toward an enormous abyss in human understanding. From the edge of that abyss, we peer anxiously through our telescopes into the fog of the unknowable. If we travel in the other direction — if we turn inward and, with a succession of ever more powerful microscopes trace the process of death down through the level of individual cells and into the molecules and atoms of which they are composed — we come once more to a fog-filled abyss, one that separates the phenomenon we call life from the cold and indifferent physical universe. And we see through our microscope a figure, peering anxiously at us through a telescope. . . . Death brings us full circle.

Sex and the Origins of Death

This page intentionally left blank

1

Death of a Cell

If you know not how to die, do not trouble yourself. Nature will in a moment fully and sufficiently instruct you. She will do it precisely right for you; do not worry about it.

—Montaigne

The average adult human being is composed of something more than a hundred trillion — 10^{14} — individual cells, each with a life of its own. The death of a human being is a direct, irreducible consequence of the death of his or her component cells. But what does death mean at the level of a single cell? And how many of our cells have to be dead before we are dead? In a complex multicellular organism like a human being, are some cells more important for being alive than others? What do we really know about these elusive "atoms of life"?

In fact we know a great deal about the cells that make up our bodies. We know, first of all, that life on earth certainly did not begin in the form of multicellular animals like us. The earth itself came into existence around five billion years ago. The initial atmosphere created by gases escaping from this newly condensed mass was very different from the air we breathe today, and the materials dissolved in the newly formed seas were also very different. The seas contained carbon- and nitrogen-based compounds which could be readily converted, under the influence of the tremendous thermal, electrical, and radioactive energies raging over the earth's early surface, into the basic building blocks of life, such as proteins and nucleic acids. These reactions have actually been reproduced in the laboratory, and the scenarios for explaining how these basic building materials arose are quite believable.

Somewhere around four billion years ago, the very first cells seem to have arisen from this inanimate matter, by processes that today can only be guessed at. The guesses made so far are not very convincing. These early cells did not assemble themselves into multicellular animals for at least two billion years after their first appearance on earth. In the beginning life consisted of nothing more than single, free-living cells. Yet whatever properties we may ascribe to life — the ability to eat, to move about, to produce offspring— were displayed by these single cells. Such organisms still exist today as bacteria, yeast, amoebae, and many other single-cell life forms. Like their forebears billions of years ago, these cells are tough. They have to be. Single cells are extremely small, and now as in the beginning each cell has to survive entirely on its own. Ultraviolet rays from the sun, as well as the oxygen in the atmosphere, pose a constant threat to the very material they are made of. The world around them is dangerous and in a constant state of flux, changing almost hourly. Temperatures shift; food and water sources come and go; the acidity and salt level of their surroundings can wander all over the map, passing in and out of the narrow range able to support life.

The first cells to appear on earth arose directly from materials contained in the "primordial soup"—the collection of bioorganic molecules generated in the high-energy reactions mentioned above. As far as we know, these conditions for producing cells from inanimate matter no longer exist on earth. Cells, whether they are single individuals or part of a multicellular organism, now arise only from other cells. Every human life begins as a single cell, formed by the union of a sperm and an ovum; approximately fifty rounds of cell division are required to produce a fully formed person, by which time the various daughter cells look as different as brain and bone, or heart and bladder. Yet each cell, despite outer appearances, actually differs from every other cell in the body in only the subtlest ways. Each is the end-product of billions of years of evolution, of nature's practice in "getting it right." And each of these near-perfect cells—with one exception — must die. We will discuss this exception a bit later.

The idea that plants and animals are made up of individual cells that correspond to and are ultimately derived (in an evolutionary sense) from the free-living, single-cell microorganisms that still permeate our environment was inspired by the use of increasingly powerful microscopes. The first descriptions of free-living cells like yeast and bacteria, or the amoebae found in freshwater ponds, began to appear in the mid-1600s. They were referred to as "animalcules," or little animals, in recognition of their status as living things. At the time, no one had the slightest idea what cells were, or of their significance as living things or as parts of living things. The notion that the cells that make up plants and animals might also be individual, self-replicating life units took two hundred years to develop, and was not firmly established until the late 1830s, when Theodor Schwann and Matthias Schleiden proposed the "Cell Theory."

With the increasing perfection of the microscope, and especially with the development in the latter half of the nineteenth century of chemical stains that could make the different parts of cells and tissues stand out from one another in sharper contrast, it was gradually realized that the cells making up a tissue have a sophisticated internal architecture, and that this architecture can be related in precise ways to the functions of the cell. The first subcellular structure to be described was the nucleus, which because of its large size had actually been discovered in the 1830s, well before the advent of staining techniques. Identification at the structural level of other parts of the cell took longer, and association of structures with cellular functions only seriously got under way after the development of the electron microscope in the 1930s and 1940s. The major working parts of the cell, called *organelles*, were still being defined into the 1980s. Even today there remain a few structures within the cell about whose functions we are not entirely certain.

Cells are the smallest living units making up our bodies. They are incredibly tiny; ten thousand of them clustered together are just visible to the unaided eye. Yet every cell contains within it, in the form of a molecule called DNA, a kind of chemical hologram of an entire human being. Each cell, at least theoretically, has the information necessary to reproduce the entire being of which it is but the hundred-trillionth part. This has actually been done in the laboratory in a limited way with frogs, and the idea of doing it in humans (and dinosaurs!) has generated more than one science fiction novel. As a practical way of making human beings, however, DNA "transplants" are a long way from becoming a threat to our present means of reproduction.

Most cells in our bodies are born — and will live and die — in complete and utter darkness. The vast majority of cells within our bodies have never seen the light of day. Unless they have managed to get in the way of an X-ray beam, none has ever felt the sting of a photon on its surface. Even the living cells of the skin, buried as they are beneath layers of dead cells, have only a minimal sense of the light, unless we insist on lying under the sun for hours on end without protection. The one exception is cells of the retina that line the back of the eye and gather light from the sun or other stars, or from man-made sources. But this thin cell layer is walled off from the rest of the body by an underlying layer of connective tissue so dense and shiny in some animals that it bounces photons right back through the retina a second time, doubling their rate of capture (a useful trick for night vision). Any photons managing to pass through this connective tissue barrier beneath the retina run into a bone wall — the thick, curving eye socket of the skull. The brain is as much in the dark as any other part of the body.

When life began on earth, cells did not live in darkness, unless they happened to be under a rock or at the bottom of the sea. They certainly did not live buried in a mass of other cells, creating their own darkness. When at last a few cells came together to form multicellular organisms, they unquestionably gained a great deal in terms of security. The inner darkness that comes from being a small part of a large biomass is a great way to escape damage from the sun. Internal environments, particularly in mammals like us, are relatively stable with respect to most of the parameters that sustain life.

But there is a downside to this improved standard of living. Cells that united to become multicellular also became soft. Once they accustomed themselves to their new environment and a life of relative ease, cells lost their toughness, their ability to cope with conditions less than ideal. As a