PREFACE

The impetus for this book comes from teaching animal physiology for many years. I found that though most life science and medical students were quite unaware of the antecedents of what they are being taught, they were interested and wanted to know more. *The Rise of Experimental Biology: An Illustrated History* attempts to satisfy this need by providing an overview of the origin and tortuous history of the science of biological function. An underlying theme is that science provides one of many explanations of the how and the why of life processes, but that it is unique because of its methodology—reason and experiment. However, there will be a running commentary that theories of biology do not develop in isolation, but are interrelated with their social context.

It is clearly impossible to hope to cover this story in a couple of hundred pages of text when hundreds of volumes by specialists have dealt with the details. Instead, I attempt to provide the merest sketches of this fascinating history. The elements are perhaps idiosyncratically selected: some conventional because as keystones they have to be mentioned, others more unusual because I find them amusing and particularly interesting. My approach then is not to give a conventional chronological list of who did what and when, but rather to provide a narrative on the highlights of the evolution of the science of biology.

An early, but important question I faced when organizing *The Rise of Experimental Biology: An Illustrated History* was how to handle references. In a conventional professional manuscript, each statement would be carefully annotated and cross-referenced. But in what is, one hopes, a popular book for general reading, such an arrangement would prove cumbersome; in any event, most of the details are common to the major science histories and readily available. Therefore, I have gathered all of my sources in the reference section of this book and list only particular references that give special information or peculiar points of view.

Peter Lutz, PhD
Department of Biological Sciences
Florida Atlantic University
Boca Raton, FL

2 The Beginnings

CONTENTS

It is part of the human condition to attempt to describe, explain, and control nature. This is seen in the Paleolithic representations of animals and ancient skull surgery. In the Mesopotamian civilization, more accurate anatomical descriptions serve more sophisticated divinational purposes. In early ancient Egypt, a specialized system of medical practice is supported by more detailed anatomy and speculation on the function of some body parts.

MYTH AND MAGIC

The compulsion to describe nature, for whatever reasons, the need to interfere physically to alleviate illness, and the drive to control one's destiny are deeply engrained human activities with roots at the beginnings of homo sapiens: The evidence is universal and ancient. For the vast majority of humankind, throughout almost all of history, natural events, such as the rising and setting of the sun and the waxing and waning of the moon, are compelling illustrations of vital significance. They are signs or omens of humans' place in an all-encompassing drama of life, a drama that involves both natural and supernatural forces.

Explanations of natural phenomena are immediate and complete in themselves. Take, for example, the terrifying phenomenon of lightning: Who did it? In the myths of Northern Europe, the answer is, the god, Thor. Why did he do it? To show great anger, as witnessed in the flash and the roar. How did he do it? By throwing a magic thunderbolt, or by striking his gigantic mallet on a great flintstone. If any further explanation is needed, Thor is a member of a large family of gods who fit into an all-embracing assemblage of supernatural beings, which gives similar explanations of natural events. These divine beings provide an overarching cosmic structure that is responsible for the past, determines the present, and controls the future. The

Fig. 2.1. Religious explanations of natural phenomena such as thunder are universal. Wooden sculpture of the Nigerian Yoruba tribe god of thunder, Shango, holding his spear. (From Peter Lutz, 2001.)

mere description of the phenomenon suffices; no further details are needed. The importance of the phenomenon lies in its relevance to the supernatural scheme of nature, and this is what is explained and argued about. Such explanations are global and ancient, and clearly satisfy a basic human need. The thunder god is universal and tenacious: The original Zeus of Greece and Guamansuri of ancient Peru; in Nigeria, the traditional god of war and thunder of the Yoruba tribe is Shango, who carries a lightning spear (Fig. 2.1). This god is still worshipped today in the African-derived cults of Central America and Brazil, and in the present-day Santeria religion of Cuba. His likeness can been purchased today in any Santeria (Botanica) shop in the Little Havana district of Miami. In English-speaking countries, we still commemorate Thor in Thursday.

But besides providing interpretations of natural phenomena, the religious belief system had to work, in the sense that it had to contain kernels of practical knowledge for supplying essential needs

(Bernal, 1965). Although diverse cultures talked a great deal of nonsense about explanations, those that survived acted with a great deal of sense. This is a necessary condition, i.e., the group's actions with respect to getting food, providing protection from disease, making tools, weapons, fortifications, and so on—all must be practical and successful to the degree that allows the tribe, city, empire to survive against natural forces and other human rivals. They must be able to predict when critically important seasonal changes will happen, such as when winter starts, when rain will come, or when to gather and when to sow the crop. To this end, the priest has sacred formulas to encourage or compel the gods to cause the sun to rise each day, or to end winter. Through this secret knowledge the priest has the power to change the future by invoking prayers that will avert, defeat or deflect pestilence. These functional requirements are embedded in all of the widely diverse particulars of the mythological formulas that regulate law and behavior in different cultures throughout the world. However, early civilizations share one common feature: The most important and essential rituals are practiced in specialized powerhouses, the temples, by expert professionals, the priests.

As societies became more complex, so did their religions. In sophisticated ancient Rome, it was believed that the world was full of little gods that had to be invoked on special occasions, even to the minutiae of life. There was the god, Vatican, who caused the infant to utter his first cry; Fabulinus, who prompted his first word; and Cuba, who guarded him when old enough to exchange the cradle for cot (Osler, 1921). The priests were responsible for interpreting exquisitely detailed omens. Specialized Roman augurs read the will of the gods from the patterns of flying birds and their sounds. But even more, there was one set of priests for eagles and hawks, and another set for swifts and owls. No war was undertaken and no decision made, no matter how small, until the priests had read the omens.

In contrast to religious dogma, natural explanations of the natural world, its properties, and their changes, do not depend on, or even use, the intervention of a god or spirit. In contrast to mythologically driven accounts, a close examination of the phenomenon is important: Natural explanations are dependent on detail. Initially, the most plausible explanation is the one that is in closest agreement with current knowledge of natural forces. This is established by argument. Later, the proposed explanations are subjected to increasingly rigorous tests of demonstration and experimentation. Here we are involved in a chain of explanations, in which the immediate natural cause has a natural cause, which itself must have a natural cause, and so on. In principle, we are on a path *ad infinitum*, or one that halts at some ultimate cause.

However, building up a corpus of description and explanation of the natural world requires the luxury of a group of people that has the leisure not to work for a living, so that they can spend their time reading, writing, and discussing: a philosopher class. The freedom of this privileged group depended on the stable social organization of the city-state, the material wealth of which was supported by the labor of an underclass, usually bound slaves. The development of a system of record-keeping, writing, which could transmit knowledge from generation to generation, was a critical element in this process. Such conditions arose in the ancient civilizations of China, the Indus Valley, Mesopotamia, and Egypt. Once a critical population mass was reached, technical revolutions had to provide the essential material bases of these civilizations. An increased population density could only be supported by higher productivity. Consequent practical innovations included the domestication of animals, higher-yield agriculture through the selection of grain crops, and the techniques of pottery, brick making, and metal work. For example, through the experience of trial and error, the Egyptian smiths gradually developed a high practical knowledge of metallurgy. They found that the hardest bronze was made of 12% tin and 88% copper, that decreasing the tin content resulted in a softer bronze, and that increasing it resulted in a more fragile product (Bernal, 1965). Increasingly accurate

anatomical descriptions also appear in these early civilizations, but they mainly serve in divination.

MESOPOTAMIA

Although civilization flourished in ancient India and China, the strongest roots for the future development of science lie in the Middle East, the true start of our story.

The area between the Tigris and Euphrates rivers, in what is now Iraq, is the site of ancient Mesopotamia, homeland of one of the world's first civilizations. Settlements there have been dated as far back as 10,000 BC. About 5000 BC, the Sumerian civilization was established. One of the greatest rulers of Mesopotamia, Hammurabi, who ruled from his capital Babylon about 1790–1750 BC, caused a massive pillar of stone to be erected, which contained the Codex of Hammurabi. Although primarily a legal document, concerned with property rights, it also laid down the law for medical and veterinary practice. A sliding fee schedule is given of payments and penalties for treatments to gentlemen, slaves, and domestic animals (Sarton, 1952). The Codex provides a fascinating picture of the robust dangers to both doctor and patient of ancient surgery, and describes the first managed health care: "If the doctor shall treat a gentleman and shall open an abscess with a bronze lancet and shall preserve the eye of the patient, he shall receive ten shekels of silver. If the doctor shall open an abscess with a blunt knife and shall kill the patient or shall destroy the sight of the eye, his hands shall be cut off or his eye be put out" (Gardner, 1965).

Veterinary surgeons were similarly regulated, but less vulnerable to such drastic malpractice consequences: "If a veterinary surgeon perform a major operation on an ox or an ass and has caused its death, he shall give the owner of the ox or the ass one-fourth of its value" (Sarton, 1952).

Several hundred cuneiform tablets concerned with medical issues have survived. These deal mostly with prescriptions for illnesses, but a few describe diseases, the causes of which were typically spirits (one spirit for one type of ailment), and

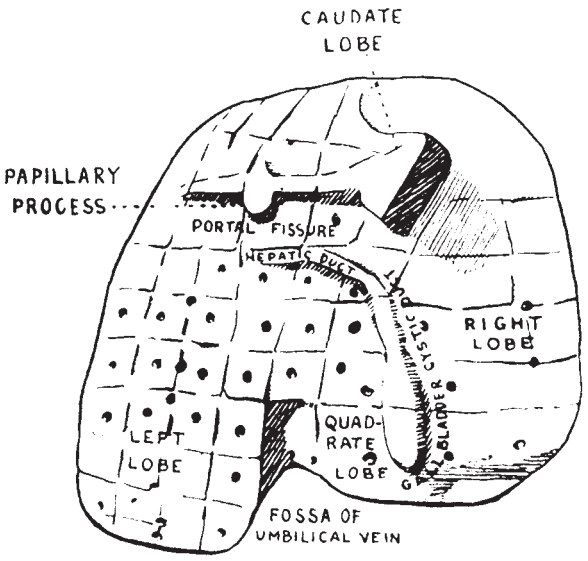

Fig. 2.2. By as early as 3000 BC, hepatoscopy had become an extraordinarily complex art in Babylonian prognostication. A clay model of a sheep's liver used to teach divination in ancient Babylonia, about 2000 BC. Anatomical features are labeled by Singer (1957). Reproduced with permission from Dover Publications.

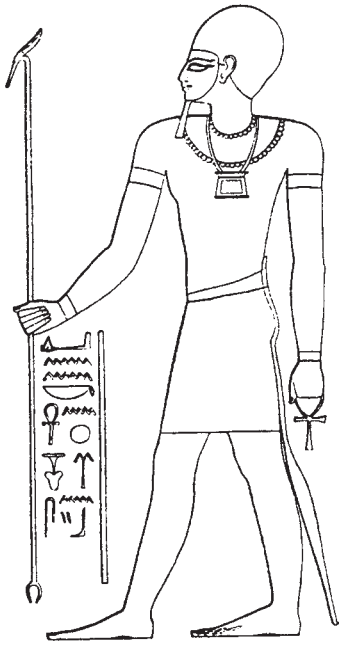

Fig. 2.3. Imhotep, who lived in the twenty-seventh century BC, was later worshipped as the god of medicine in Egypt, and identified with the Greek god of medicine, Asclepius. A representation of Imhotep, the Egyptian god of medicine, Temple of Ptah at Karnak. (From Hurry, 1928.)

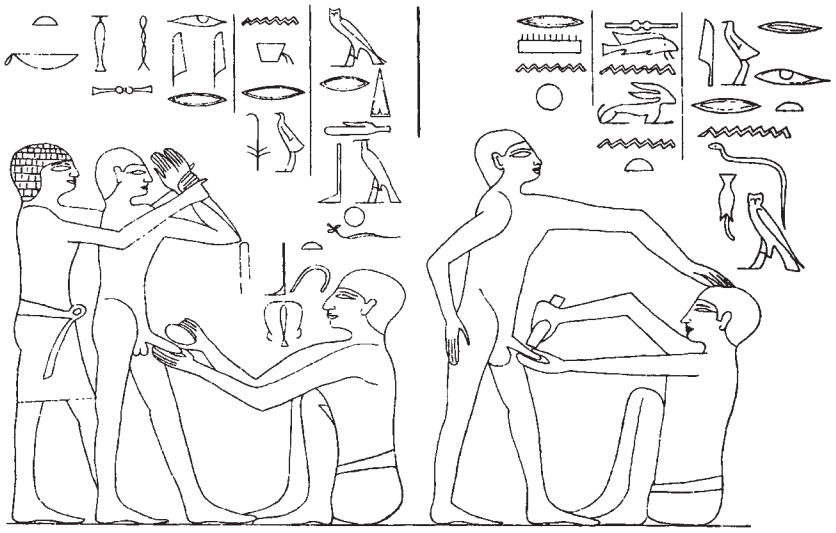

Fig. 2.4. The earliest representation of circumcision. From the Necropolis of Sakkara, dated at the beginning of sixth dynasty. (From Castiglioni, 1958.) A stone knife was used for the operation.

the treatments often aimed at the expulsion of the malingering spirits (Frey, 1975).

There is abundant evidence of an interest in anatomy in the Babylonian-Sumerian Empire. But the details are sharply pragmatic—almost all are connected to the art of divination, which is the telling of the future through inspection of the organs of sacrificed animals.

Organ divination was an important and specialized skill, one that required many years of training. Of all the organs, the liver, from its size, central position, and richness in blood, was the most impressive. Furthermore, for generations blood was believed to be the essence of life, so the blood-rich liver was naturally regarded as the seat of life. Although other organs of the sacrificial animal had their own specialized uses, reading the liver—hepatoscopy—was the most important way to learn the divine will.

By as early as 3000 BC, hepatoscopy had become an extraordinarily complex art in Babylonian prognostication. The lobes, gallbladder, swellings of the upper lobe, and their markings, were all carefully inspected by the priest. A large number of texts were written on this topic, and many illustrative and anatomically accurate clay models survive, made to assist or teach liver divination. The earliest known, dating from about 2000 BC, is a model of a sheep's liver, with an included divination text (Fig. 2.2). In many of these models, the liver is divided into lobes, then into squares, with each square having its own special prognostication. Surviving texts provide some of the rules that the priests used in their interpretations. For example, a gallbladder, swollen on the right side, indicated superiority in the king's army, and was favorable; but swelling on the left side indicated success of the enemy, and was unfavorable. A long bile duct pointed to a long life (Jastrow, 1935).

EGYPT

Ancient Egypt is the first civilization with written records that show an extensive interest in medicine. However, like all of the early civilizations, Egyptian biological science was essentially empirical and pragmatic, dealing directly with magic and healing, and with little interest in theory.

A hierarchical medical profession was established early in Egypt. Imhotep (Fig. 2.3), who lived in the twenty-seventh century BC, was considered by Osler (1921) as "the first figure of a physician to stand out clearly from the mists of antiquity." He

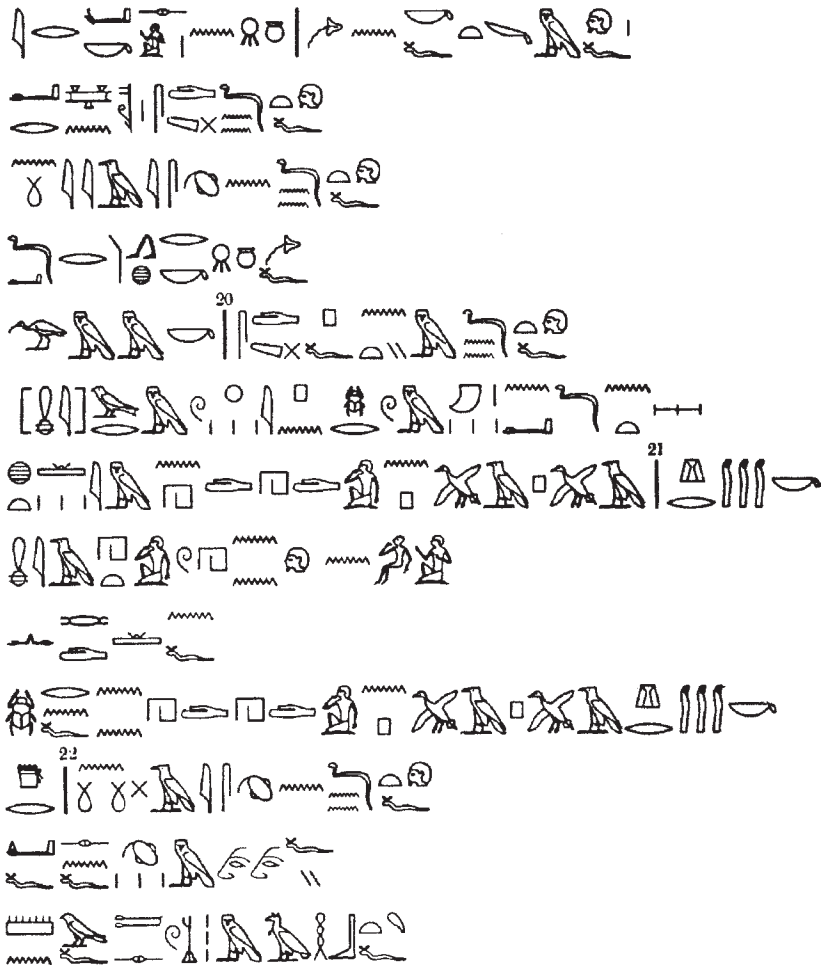

Fig. 2.5. Hieroglyphic of case six in the Edwin Smith surgical papyrus. (From Breasted, 1930.)

was chief minister to Djoser, the second king of Egypt's third dynasty. In later times, Imhotep was worshipped as the god of medicine in Egypt, and was identified with the Greek god of medicine, Asclepius, in Greece. A physician class soon developed that became powerful and specialized. There were physicians of the eye, stomach-bowel physicians, and "guardians of the anus" (Sarton, 1952).

The Egyptian concept of life differed from that of Mesopotamian medicine in that while the latter saw the liver as the source of life-giving blood, the Egyptians apparently gave a greater emphasis to the act of respiration as central to life. They believed, quite accurately, that life failed when respiration stopped. But blood was still important. *The Book of the Dead* relates how the gods Hu and Lia arose from the blood that gushed from the sun god Ra, when he cut off his penis, and mummies were painted red to give them the strength of blood (Castiglioni, 1958).

Many medical papyri have been preserved, indicating the vast amount of biological/medical knowledge in ancient Egypt. The oldest are a half-dozen or so from the period between 2000 and 1500 BC, which are probably based on older texts dating to around 3000 BC (Frey, 1975). One of the oldest, the Kahun medical papyrus (ca. 2000 BC), is the most ancient document on gynecology known. The largest, the Ebers papyrus, is 20 m

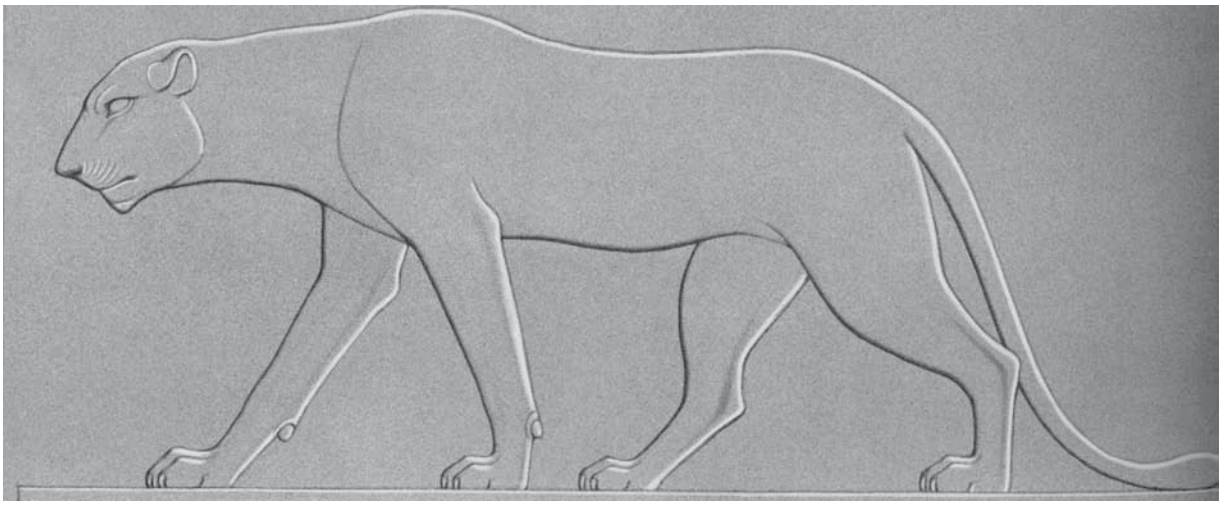

Fig. 2.6. Some early Egyptian animal sculptures show a beautiful naturalism. A 3500 year old bas-relief, from the temple of Assassif, of an Egyptian panther.

long, with more than 2000 lines. It begins grandly: "Here begins the book of the preparations of medicines for all parts of the bodies of a person" (Stevens, 1966). The Ebers papyrus contains 877 recipes or prescriptions for a great variety of diseases or symptoms, systematically arranged and treated in an orderly fashion, and some instructions for surgery. For example, according to the Ebers papyrus, male circumcision was performed at the age of fourteen (Fig. 2.4). The circumcision of girls was also of general use in ancient Egypt (Castiglioni, 1958).

The most famous medical papyrus, the Edwin Smith surgical papyrus, written about 1700 BC, is much shorter, being only about 5 m long, and is available to us in a widely quoted translation by Breasted (1930). It deals, not with general recipes, but with definite cases. The Smith papyrus contains a systematic treatment of 48 cases of injury and wounds, starting at the head and going to the shoulder region. It is likely that the rest of the body was dealt with in a continuation of the manuscript, now lost (Sarton, 1952).

The cases are systematically discussed under the following formal arrangement: title, examination, diagnosis, treatment, and glosses (an explanation of technical terms used). In 13 cases, the opinion is that the wound is fatal, and not to be treated, i.e., there is a scientific interest in recording and discussing observable facts for which there is no treatment (translation from Breasted, 1930).

One example (case six [Fig. 2.5]) deals with a gaping wound on the head, penetrating the bone and revealing the brain.

Title: Instructions concerning a gaping wound in his head, penetrating to the bone, smashing his skull, (and) rendering open the brain of his skull.

Examination: If you examine a man having a gaping wound in his head, penetrating to the bone, smashing his skull, and rendering open the brain of his skull, you should palpitate his wound. Should you find that smash which is in his skull like those corrugations which form in molten copper, and something therein throbbing, fluttering under your fingers, like the weak place of an infant's crown before it becomes whole when it has happened there is no throbbing and fluttering under thy fingers until the brain of (the patient) is rent open-and he discharges blood from both nostrils, and he suffers with stiffness in the neck.

Diagnosis: following this detailed description is rather an anti-climax: "an ailment not to be treated."

Egyptian medicine incorporated many fundamental physiological observations about the living body that had been made from ancient times. But the Egyptians' very complicated religion ruled all. For them, the distinction between life and death was of especially deep concern. The living body is warm, breathes, and moves. Death is the absence of these qualities, and the corpse is cold and still. The heart was the center of life. It is the source of life-giving heat and the house of the soul. The rapid beating of the heart in anger, fear, and surprise indicated that these emotions arose in the heart. It was believed that the pulse was the heart "speaking" to the rest of body through the blood vessels (French, 1978a). The Egyptians, accordingly, treated the heart with special reverence during embalming: It was elaborately wrapped and carefully preserved in a special jar, or placed back in the body cavity. The brain, by contrast, was considered worthless. It was removed part by part by a hook through the nose, and discarded.

Some early Egyptian animal sculptures show a beautiful naturalism (Fig. 2.6). In the period of the Middle Kingdom (starting about 2000 BC), however, the nascent rational and empirical spirit seen in the Edwin Smith papyrus gradually waned and Egyptian science became fossilized, subsumed into magic and mysticism. An example of mystical logic, which will be referred to later; the number 4 became especially revered; there were four columns to support the roof of the temple, four sides of the pyramid, and medicine was to be taken four times a day. We see then that in some early civilizations, such as in Mesopotamia and Egypt, there was an initial attempt to ascribe natural causes to some natural phenomena. But the effort was not sustainable and was engulfed by overwhelming, conservative religious forces.