Aristotle on the Brain

CHARLES G. GROSS

Aristotle argued that the heart was the center of sensation and movement. By contrast, his predecessors, such as Alcmaeon, and his contemporaries, such as the Hippocratic doctors, attributed these functions to the brain. This article examines Aristotle's views on brain function in the context of his time and considers their subsequent influence on the development of the brain sciences. The Neuroscientist 1:245–250, 1995

KEY WORDS *Aristotle, History of science, Greek science, Localization of function*

Aristotle's name is invariably linked to philosophy; indeed, for centuries, he was known as "The Philosopher." However, he was also the leading biologist of classical antiquity and one of the greatest biologists of all time. He is usually considered the founder of comparative anatomy, the first embryologist, the first taxonomist, the first evolutionist, the first biogeographer, and the first systematic student of animal behavior (1–4, but cf. 5). Not only was he important to the development of biology, but biology was very important in his own development as a thinker. Over a quarter of his writings were on biology, and his biological work was crucial in distancing him from his teacher, Plato (6–8). Beyond biology, he was a true universal genius, writing with permanent impact on such subjects as logic, metaphysics, art, theater, psychology, economics, and politics. His formerly dominating influence on the physical and biological sciences, however, has largely disappeared in the last several centuries.

Perhaps Aristotle's most egregious scientific error fell in the domain we now call neuroscience: he systematically denied the controlling role of the brain in sensation and movement, giving, instead, this function to the heart. I begin consideration of this enigma by summarizing the views on brain function held by the Greek philosopher-scientists before Aristotle. Then, the arguments and evidence Aristotle put forward for his curious views are presented. Finally, I examine the influence of Aristotle on the subsequent development of the brain sciences. Figures 1 and 2 provide some orientation in time and space for this article.

From the Department of Psychology, Princeton University, Princeton, New Jersey.

Address reprint requests to: C. G. Gross, Dept. of Psychology, Princeton University, Princeton, NJ 08544.

Alcmaeon of Croton

Formal science, the idea that the universe is a complicated mechanism working according to fixed laws that could be understood through human reason, began with the pre-Socratic philosopher-scientists Thales, Anaximander and Anaximenes in sixth-century BCE Miletus, a Greek city in Asia Minor (1, 9). By the middle of the fifth century, there were three major centers of Greek medical science: Croton, in what is now southern Italy, Agrigentum on the south coast of modern Sicily, and Cos, an island off modern Turkey. The oldest of these medical centers was in Croton, and its most famous member was Alcmaeon. Croton was also the site of the Pythagorean brotherhood, and there seems to have been considerable interaction between the Pythagoreans and the medical school (10–12).

Alcmaeon was the first writer to champion the brain as the site of sensation and cognition. He also seems to have been the first practitioner of anatomic dissection as a tool of intellectual inquiry. His most detailed dissections and theories were on the senses, particularly vision. Alcmaeon described the optic nerves, noted that they "came together behind the forehead" (which is why, he opined, the eyes move together) and suggested that they were "light-bearing paths" to the brain. He removed and dissected the eye, and observed that it contained water. Observations of what are now called phosphenes after a blow to the eye led him to conclude that the eye also contained light (fire) and that this light was necessary for vision (11, 13, 14). This idea that the eye contains light became the basis of theories of vision that persisted beyond the Renaissance. Indeed, Alcmaeon's idea of light in the eye was only disproved in the middle of the eighteenth century (15) .

Among the other pre-Socratic philosopher-scientists who adopted and expanded on Alcmaeon's view of the functions of the brain were Democritus, Anaxagoras, and Diogenes (10, 13, 14, 16). Democritus developed a version that became very influential because of its impact on Plato. Specifically, Democritus taught that everything in the universe is made up of atoms of a particular size and shape. The psyche (soul, mind, vital principle) is made up of the lightest, most spherical and fastest moving atoms. Although the psychic atoms are dispersed among other atoms throughout the body, they are much more numerous in the brain. Slightly cruder atoms are concentrated in the heart, making it the center of emotion, and still cruder ones are located in the liver, which consequently is the seat of lust and appetite. This trichotomy developed into Plato's hierarchy of the parts of the soul in which there is no question about the supremacy of the brain. As he put in the *Timaeus* (17), "It is the divinest part of us and lord over all the rest." Then, in Galen's medical theorizing, the three soul-parts became the three pneumas of humoral physiology that dominated medical thought for so many centuries (18, 19).

However, Alcmaeon's view of the hegemony of the brain was not universal among the pre-Socratic philosopher-scientists. For example, Empedocles, the leading member of the medical center at Agrigentum, taught that the blood was the medium of thought, and the degree of intelligence depended on the composition of the blood (14, 16). Thus, for him, the heart was the central organ of intellect and the seat of mental disorder.

The general idea of the heart as the seat of intelligence and emotion was not new. It had been held in many earlier cultures such as the Egyptian, Mesopotamian, Babylonian, and Indian (20, 21). It is reported to be common among nonliterate cultures as well (20), as illustrated by the oft-quoted remark of a Pueblo chief to C.G. Jung (22), "I know you white men think with the brain. That

ISSN 1073-8584

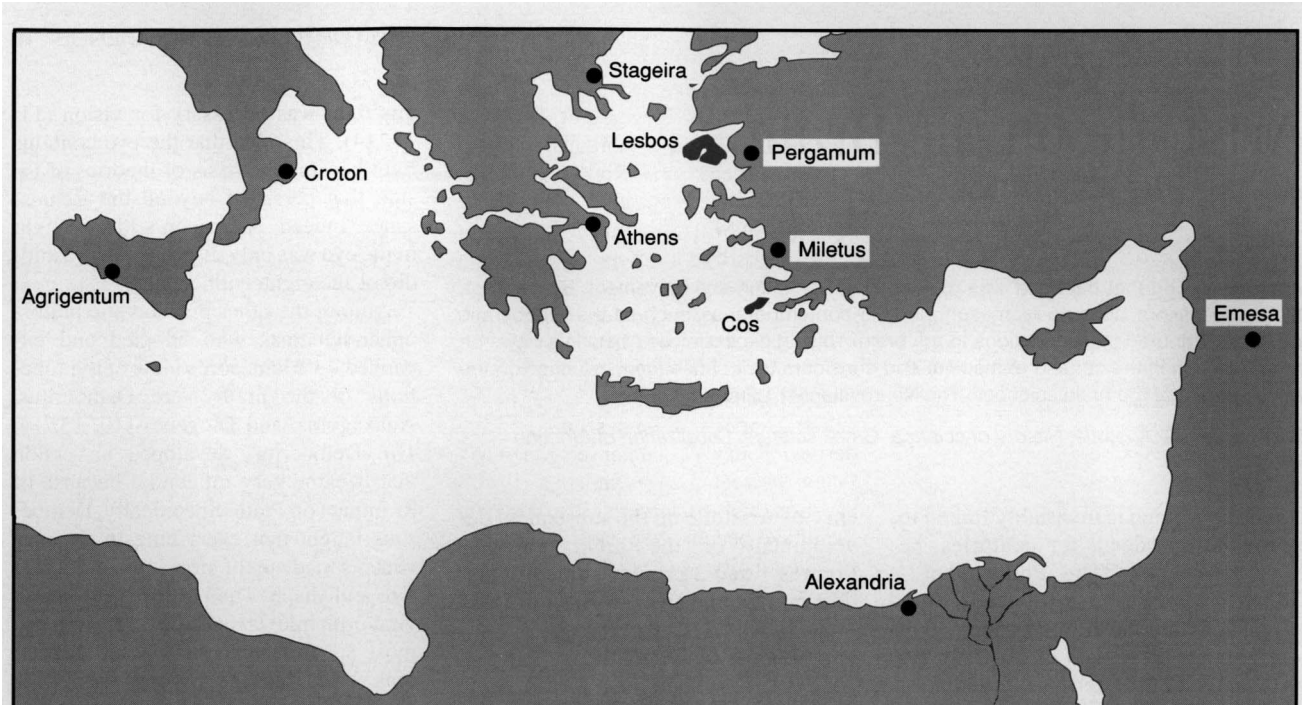

Fig. 1.

accounts for your shortcomings. We red men think with the heart." Ancient Chinese medicine had rather more complicated views than the relatively simple heart-centered ones of other ancient cultures, but it also thoroughly ignored the brain (23, 24). In fact, the role of the brain in perception and cognition did not enter Chinese thought until the Jesuit Matteo Ricci's treatise (in 1595, in Chinese) on the art of memory, which he wrote as part of his campaign to convert the scholar class (25).

The Hippocratic Doctors

The third great center for the teaching and practice of medicine in the fifth century BCE was the island of Cos, and its most famous member was Hippocrates. The first large body of Western scientific writings that have survived is the Hippocratic corpus. Although there is no question that Hippocrates was a real historical figure, it is not clear which of the writings called Hippocratic were actually written by him (26). The Hippocratic corpus consists of more than 60 treatises, which vary enormously in style and technical level and which were not written by one author, or even in one period.

Unlike Alcmaeon and the Croton School, the Hippocratic doctors did not practice dissection and their knowledge of anatomy was slight. However, like the pre-Socratic thinkers in general, they rejected supernatural causes of disease and sought natural explanations through observation and extended case studies (1, 10, 12). Similarly detailed accounts of disease processes were rare until after the Renaissance and even then tended to be advertisements for the skill of the physician rather than empirical studies.

The Hippocratic work of greatest relevance to brain function is the famed essay "On the Sacred Disease" (27), which is epilepsy. The work, probably designed as a lecture for laymen, opens with an homage to reason and the rejection of superstition:

> I do not believe that the Sacred Disease is any more divine or sacred than any other disease, but, on the contrary, has specific characteristics and a definite cause. . . .
>
> It is my opinion that those who first called this disease 'sacred' were the sort of people we now call witch-doctors, faith-healers, quacks, and charlatans. These are exactly the people who pretend to be very pious and to be particularly wise. By invoking a divine element they were able to screen their own failure to give suitable treatment and so called this a 'sacred' malady to conceal their ignorance of its nature.

The author has no doubt that the brain is the seat of this disease. As to the general functions of the brain, he is equally clear:

> It ought to be generally known that the source of our pleasure, merriment, laughter, and amusement, as of our grief, pain, anxiety, and tears, is none other than the brain. It is specially the organ which enables us to think, see, and hear, and to distinguish the ugly and the beautiful, the bad and the good, pleasant and unpleasant. . . . It is the brain too which is the seat of madness and delirium, of the fears and frights which assail us, often by night, but sometimes even by day; it is there where lies the cause of insomnia and sleep-walking, of thoughts that will not come, forgotten duties, and eccentricities.

Furthermore, he states, neither the diaphragm nor the heart has any mental functions, as some have claimed: "Neither of these organs takes any part in mental operations, which are completely undertaken by the brain."

What then is the cause of epilepsy, the so-called sacred disease? He goes on to say that it attacks only the phlegmatic, those with an excess of phlegm or mucus.

> Should . . . routes for the passage of phlegm from the brain be blocked, the discharge enters the blood-vessels . . . this causes aphonia, choking, foaming at the mouth, clenching of the teeth and convulsive movements of the hands; the

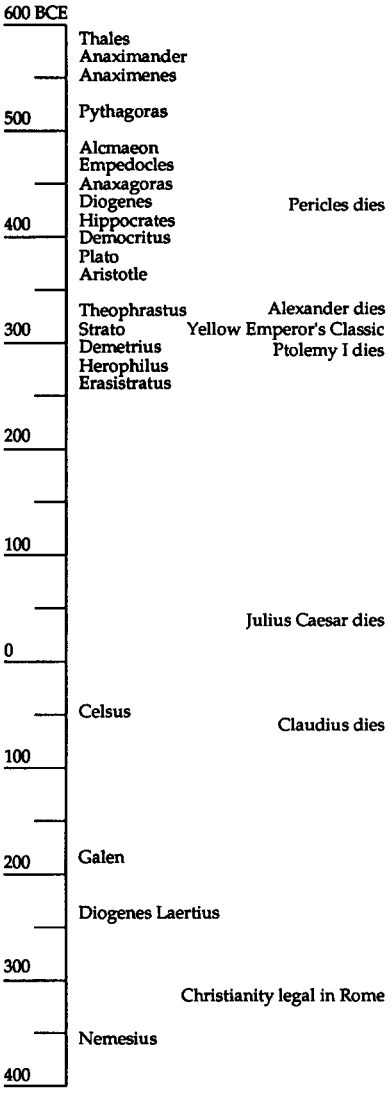

Fig. 2.

eyes are fixed, the patient becomes unconscious and, in some cases, passes a stool.

These extracts from "On the Sacred Disease" typify the best of Hippocratic medicine: a total absence of superstition, accurate clinical description, ignorance of anatomy and a physiology, which is largely an absurd mixture of false analogy, speculation, and humoral theory. Perhaps the entire history of medicine can be viewed as the narrowing of the gap between the medical empiricism characteristic of the School of Cos and the knowledge of structure and mechanism sought by the School of Croton.

Finally, it should be noted that the "Hippocratic Oath" not only had no connection with the Hippocratic school, but is quite deviant from mainstream Greek medical and social practice in several ways (28). In its original form, it forbids both suicide and abortion, but, in fact, neither was censured or illegal in Hippocratic times, or more generally, in classical Greece and Rome. The oath also forbids surgery. Although surgical intervention was not common, it was definitely used by the Hippocratic doctors to drain pus, set fractures, and reduce dislocations. Finally, Hippocratic doctors, like most others before and after, taught for a fee despite the oath's injunctions against such practices. The so-called Hippocratic oath seems to have derived from a much later secret neo-Pythagorean sect that was antisuicide, antiabortion, and antisurgery. The oath may then have become popular with the rise of Christianity, because the Church was opposed to suicide and abortion, and with the separation of medicine from the "lower craft" of surgery.

Aristotle on the Brain and Heart

Aristotle was born in 384 BCE in Stageira to a medical family. His father, who had been personal physician to Amyntas II, King of Macedonia (father of Philip II), died at a young age, and Aristotle's early education was probably provided by his father's fellow physicians. In those days, as now, a well-educated physician needed some general culture, so at the age of 17, he was sent off to Plato's Academy in Athens. He stayed there for 20 years and never did begin his medical training.

When Plato died in 347, his nephew took over the academy, and Aristotle left Athens with some friends for the island of Lesbos and the adjacent mainland where he apparently spent much time studying marine biology. Philip then appointed him private tutor to his son, Alexander, until, at age 16, Alexander became regent of Macedonia and had little time for further academic studies. Aristotle returned to Athens in 335 and founded a new school and research center, the Lyceum. It received financial support from Alexander who, according to Pliny, also sent it biological specimens as he proceeded to conquer the known world. Thirteen years later and a few months before his death, Aristotle was driven from Athens by the ascent of anti-Alexandrian factions. Aristotle, or so Diogenes Laertius, and other ancient authorities tell us, was small, lisping, sarcastic, arrogant, elegant, and happily married (1, 10).

Now let us turn to Aristotle's views on the brain, which have embarrassed and puzzled historians and scientists from Galen of Pergamum, who "blushed to quote" them (19, 29, 30). Aristotle believed that the heart and not the brain was the center of sensation and movement:

> And of course, the brain is not responsible for any of the sensations at all. The correct view [is] that the seat and source of sensation is the region of the heart (PA656a, see Box).
>
> . . . the motions of pleasure and pain, and generally all sensation plainly have their source in the heart (PA666a).
>
> . . . all sanguineous animals possess a heart, and both movement and the dominant sense perception originate there (SW456a).
>
> . . . in all sanguineous animals the supreme organ of the sense-faculties lies in the heart" (YO469a).

Table 1 summarizes Aristotle's arguments for the heart and against the brain as the center of sensation and movement. Aristotle was well aware of the earlier claims for the dominance of the brain as opposed to the heart, such as those of Alcmaeon, Plato, and Hippocrates, and repeatedly argues against their "fallacious" views (PA656a,b). For example, he claims his predecessors say that the scarcity of flesh around the brain is in order for sensation to get through. But, Aristotle answers that the fleshlessness is in accordance with the cooling function of the brain and furthermore, the back of the head is also fleshless, but there are no sense organs there. They also mention that the sense organs are placed near the brain, but Aristotle gives a number of alternate reasons for that. For example, the eyes face frontward so that we can see along the line we are moving, and ". . . it is reasonable enough that the eyes should always be located near the brain, for the brain is fluid and cold, and the sense organ of sight is identical in its nature with water." The ears are located on the sides of the head to hear sounds from all directions. In any case, there are animals who hear and smell and don't have these organs in their head. Furthermore, there are sense organs in the head because the blood is especially pure in the head region, which makes for more precise sensation.

Galen and many subsequent historians of medicine are somewhat unfair in claiming that Aristotle simply dismissed the brain as cold and wet. Rather, for Aristotle, the brain was only second to the heart in importance and was essential to

Table 1. Aristotle's Arguments for the Heart and against the Brain as the Center for Sensation and Movement

Heart	Brain
1. Affected by emotion (PA669a)	1. Not affected (PA652b, 656a)
2. All animals have a heart or similar organ (GA771a, PA665b)	2. Only vertebrates and cephalopods have one, and yet other animals have sensations (PA652b)
3. Source of blood, which is necessary for sensation (PA667b)	3. Bloodless and therefore without sensation (HA494a, 514a, PA765a)
4. Warm, characteristic of higher life (SS439a)	4. Cold (PA652, HA495a5)
5. Connected with all the sense organs and muscles, via the blood vessels (GA744a, HA492a, 469a, GA781a)	5. Not connected with the sense organs or the connection irrelevant (PA652b, HA503b)
6. Essential for life (YO469a, Pa647a)	6. Not so (HA532a, GA741b)
7. Formed first, and last to stop working (GA741b)	7. Formed second (GA674b)
8. Sensitive (SS439a, PA669a)	8. Insensitive: If the brain of a living animal be laid bare, it may be cut without any signs of pain or struggling (PA652b, 656a)
9. In a central location, appropriate for its central role (PA670a)	9. Not so

the functioning of the heart. The heart together with the brain formed a unit that controlled the body. The heart, which is naturally hot, he argued, "must be counterbalanced, in order to attain the mean, the true and the rational position. Thus, the brain, which is naturally cold, tempers the heat and seething of the heart (PA652b).

> For if the brain be either too fluid or too solid, it will not perform its office, but in the one case will freeze the blood and in the other will not cool it at all, and thus cause disease, madness and death. For the cardiac heart and the center of life is most delicate in its sympathies and is immediately sensitive to the slightest change or affection of the blood or the outer surface of the brain (PA653b).

Aristotle gave the following explanations for the cold nature of the brain: 1) the blood which it contains in its vessels is thin, pure and easily cooled (SS444a); 2) the vessels on and in the brain are very thin and permit evaporation, cooling the brain (SW458a); and 3) when the brain is boiled and the water in it evaporates, hard earth is left, indicating that the brain is made of water and earth, both of which are intrinsically cold (PA653a). In order that the brain is not completely cold, it receives a moderate amount of heat from branches of the aorta and the vena cava that end in the membrane that surrounds the brain (PA652b). When the brain cools the hot vapor reaching it from the heart, phlegm is produced. This idea that the brain produces phlegm is also found in "The Sacred Disease," as noted above, and is fossilized in our own term "pituitary," coming from the Latin "pituita," which means phlegm. Man's brain, according to Aristotle, is the largest and moistest brain for its size (HA494b, PA653a). This is because in man, the heart is hottest and richest and must be counterbalanced, for man's superior intelligence depends on the fact that his larger brain is capable of keeping the heart cool enough for optimal mental activity (PA648a,650b-51a). (Woman's brain is smaller than man's [PA653b], a view of Aristotle's that persisted much longer than his view of the mental functions of the heart.) Thus, Aristotle did not merely dismiss the brain as cold and wet. Indeed, it would have been unlike him to dismiss any organ, for he thought none to have been made without a function to perform. Rather, he believed the brain to play an essential, although subordinate, role in a "heart-brain" system that was responsible for sensation; indeed, man's superior intelligence is credited to his large brain.

Although Aristotle may have not ignored the brain quite as much as is often claimed, it remains puzzling why he made such a startling error and took such a different view from Alcmaeon and the Hippocratic doctors, and above all from his teacher Plato. Aristotle had adduced anatomical, physiological, comparative, embryological, and introspective evidence for his view of brain function. But there was an essential approach absent. This was the clinical approach, the study of the brain-injured human. The two champions of the hegemony of the brain, Alcmaeon and Hippocrates, were both practicing physicians. The evidence that both had given in support of their opinions was strictly clinical. Because there is no evidence of systematic experiments on the brain and nervous system until Galen in the second century, the accidents of nature were the only sources of information

Box 1: A Note on Classical Sources

All the works of the pre-Socratic philosopher-scientists are lost. All we have are extracts collected by the ancient doxographers. These were assembled by H. Diels at the beginning of the century and translated into English by Freeman (14).

Aristotle's works here, and more generally, are cited by the page numbers given by I. Bekker in the nineteenth century. I use the following abbreviations for individual works:

GA, Generation of Animals, trans. A.L. Peck, Harvard, Cambridge, 1942.
HA, History of Animals, trans. A.L. Peck, Harvard, Cambridge, 1965.
PA, Parts of Animals, trans. A.L. Peck, Harvard, Cambridge, 1955.
SS, On Sense and Sensible Objects in Parva Naturalia, trans. W.S. Hett, Harvard, Cambridge, 1957.
SW, On Sleep and Waking in Parva Naturalia, trans. W.S. Hett, Harvard, Cambridge, 1957.
YO, On Youth and Old Age in Parva Naturalia, trans. W.S. Hett, Harvard, Cambridge, 1957.

Von Staden (37) has collected and translated the fragments of Herophilus, and Dobson (38) has done so for Erasistratus. Other ancient sources are given in the references.

about what the brain did. It is hard to conceive of Aristotle, in the course of his strictly zoological observations and dissections, coming across evidence strongly contradicting his view of the brain and heart. It seems clear that he never dissected a human, and of the 49 animals he did dissect, from elephant to snail, the majority were cold blooded (31), as were the two, chameleon and turtle, that he obviously vivisected (HA503b, YO486b). These did indeed have "cold and wet" brains, and the connections of the sense organs with the heart might have seemed more prominent than those with the brain. On the other hand, he dissected enough vertebrate brains to describe the two covering membranes (HA494b, 495a), the two symmetrical halves (PA669b), and a "small hollow" in the middle (HA495a), perhaps the lateral ventricles. Finally, it should be noted that Aristotle never localized such psychological faculties as imagination, reasoning, or memory in the heart or any place else, but viewed them as activities of the whole organism.

Despite (or, perhaps, because of) his father's profession, Aristotle at no time seemed interested in medicine or medical writing. Indeed, medicine appears to be one of the few things that this polymath was not interested in. And, in the fourth century BCE, the study of human brain injury was the most likely way of getting a "more correct" view of the brain than Aristotle had. In fact, one of the few places where he approaches a correct view of brain function is in the rare "clinical" passage quoted above (PA653b), in which he suggests that mental disease follows from a malfunctioning of the cooling functions of the brain. Six hundred years later, Galen's observations of human head injuries led him to perform the first recorded experiments on the brain (using piglets) (32), and his observations of spinal injuries of gladiators led directly to his brilliant series of experiments on the effects of spinal cord transection (33). Even today, it is often primarily clinical data that inspire experiments on animal brains. Aristotle was a "pure" biologist, not an applied one, and in his day, the methodology of academic biology was incapable of yielding the correct view of the brain's role.

Aristotle and the Birth of Human Neuroanatomy at the Alexandrian Museum

Despite his fallacious views of brain function, Aristotle actually facilitated the subsequent development of the study of the brain. At the most general level, his stress on the importance of dissection coupled with his prestige encouraged others to perform anatomical studies (11). More specifically, he played several roles, albeit indirect ones, in the founding of the great Museum at Alexandria, and it was here that systematic human neuroanatomy began. The museum was founded at the end of the fourth century BCE by Ptolemy I, the first Greek ruler of Egypt, one of Alexander's generals and his friend from boyhood. It was a vast state-supported institute for research, perhaps like some combination of the National Institutes of Health and the Institute for Advanced Study. More than a hundred professors lived communally and had their salaries and expenses paid. The museum included lecture and study rooms, an astronomical observatory, a zoo, a botanical garden, and dissecting and operating rooms (34, 35). Its huge library was named a Wonder of the Ancient World (36).

In several ways, the museum was a continuation and expansion of Aristotle's school, the Lyceum (10, 34). First, its founder Ptolemy I had been a young pupil of Aristotle, along with Alexander. Presumably, Aristotle stressed biology in their tutorials because that was his major interest at the time. Second, Demetrius and Strato, who were both students of Theophrastus, Aristotle's long-term collaborator and his successor as head of the Lyceum, were called to Alexandria by Ptolemy to advise him on the organization of the museum. (Ptolemy tried, unsuccessfully, to hire Theophrastus himself). Third, the core of the library's collection is thought to have been gathered by Demetrius, at least in part, from Aristotle's own collection. As Strabo, the first-century historian and geographer, later put it, "Aristotle taught the kings of Egypt how to organize a library" (36).

Thus, it was in the shadow of Aristotle that the great museum anatomists, Herophilus and then Erasistratus, began the systematic study of the structure of the human body, particularly of the nervous system. They provided the first detailed, accurate description of the human brain, including the ventricles (37–39). Herophilus and Erasistratus and Western scientists thereafter had no question about the dominant role of the brain in sensation, thought, and movement. Herophilus claimed that the fourth ventricle was the "command center," a view rejected by Galen, who, instead stressed the importance of brain tissue itself. (The stoic philosophers, particularly Chrysippus, did continue to insist on the dominant role of the heart [30]. The localization of the Aristotelian psychological functions in three spherical ventricles was a later, strictly medieval religious construction, neither classical nor scientific, and began about 600 years later with Nemesius, Bishop of Emesa [40–42]. Its reverberations continued well into the nineteenth century [43]).

The immediate cause of the extraordinary surge of interest in anatomy in second-century Alexandria was that it was the first time and place where systematic and open dissection of the human body could be performed. Previously, anatomical dissections had been performed only on animals. The Greek reverence (and dread) of the dead human body had made its dissection quite impossible. What made Alexandria different? A number of factors seem to have come together (34, 37, 39). One was that Herophilus and Erasistratus had the full support of a totalitarian regime determined to glorify itself through the achievement of its scientists. As absolute rulers in a foreign land, the Ptolemys brought few inhibitions with them. A second factor must have been that dissection of the human body for the purposes of mummification had been practiced in Egypt for centuries, and, thus, the general cultural background of Egypt undoubtedly helped make human dissection possible. However, it is very unlikely that the Greek anatomists had any contact with the Egyptian embalmers, as the social gap between the Greeks in Alexandria and the natives surrounding them seems to have been enormous (34). Another factor may have been the changes in philosophical attitudes toward dying and the human corpse that were becoming common by this time (44). After all, Aristotle had taught that after death the body was no more than a physical frame without feeling or rights.

The uniqueness of the Alexandria-anatomy nexus is revealed by the fact that not only was human dissection practiced first in Alexandria, but Alexandria was the first and virtually the only place where human vivisection was systematically performed for scientific purposes (37, 39). As Celsus, the Roman historian of medicine, put it (37):

> It is therefore necessary [for medical students] to dissect the bodies of the dead and examine their viscera and intestines.

> Herophilus and Erasistratus, they say, did this in the best way by far when they cut open men who were alive, criminals out of prisons, received from kings. And while breath still remained in these criminals, they inspected those parts which nature previously had concealed . . . Nor is it cruel, as most people maintain, that remedies for innocent people of all times should be sought in the sacrifice of people guilty of crimes, and only a few such people at that.

Vivisection of humans was never systematically practiced again (until the Third Reich). Even the dissection of human cadavers disappeared in the West until it was revived in the new medieval universities, and then initially only for forensic, not medical or scientific, purposes (18).

The Legacy of Aristotle's Views on the Brain

The debate between Aristotle's advocacy of the hegemony of the heart and Alcmaeon's championing of the brain, particularly as transmitted through Plato's *Timaeus*, continued in the Arab world and then in medieval and Renaissance Europe (45). A common resolution was to combine the two views. For example, the great Arab Aristotelian and physician Ibn Sina (Avicenna) did this by placing sensation, cognition, and movement in the brain, which in turn he believed was controlled by the heart (46). Similarly, according to the thirteenth-century Hebrew encyclopedist Rabbi Gershon ben Shlomoh d'Arles (47), "the brain and heart share functions so when one . . . is missing, the other alone continues its activities . . . by virtue of their partnership." As Scheherazade (48) tells it on the 439th night (through Richard Burton), when the Caliph's savant asks the brilliant slave girl Tawaddud, "Where is the seat of understanding?" she answers, "Allah casteth it in the heart whence its illustrious beams ascend to the brain and there become fixed." And Portia's song in the *Merchant of Venice* (49) asks:

Tell me where is fancie bred,
Or in the heart or in the head.

Acknowledgements

I thank Maggie Berkowitz (then Angus) and also G. Berman, J. Cooper, M.F.A. Graziano, N. Rebmann, A. Repp, and H.R. Rodman for their help.

Selected References

1. Sarton G. A history of science, vol. I. Ancient science through the golden age of Greece. Cambridge: Harvard University Press 1959.
2. Needham J. A history of embryology. Cambridge: Cambridge University Press 1959.
3. Mayr E. The growth of biological thought. Cambridge: Harvard University Press 1982.
4. Nordenskiold E. The history of biology. New York: Tudor 1928.
5. Medawar PB, Medawar JS. From Aristotle to Zoos. Cambridge: Harvard University Press 1983.
6. Grene M. A portrait of Aristotle. London: Faber and Faber 1963.
7. Gotthelf A, Lennox JG, editors. Philosophical issues in Aristotle's biology. Cambridge: Cambridge University Press 1987.
8. Devereux D, Pellegrin P, editors. Biologie, logique et métaphysique chez Aristotle. Paris: Editions CNRS 1990.
9. Schrodinger E. Nature and the Greeks. Cambridge: Cambridge University Press 1954.
10. Longrigg L. Greek rational medicine: philosophy and medicine from Alcmaeon to the Alexandrians. London: Routledge 1993.
11. Lloyd GER. Alcmaeon and the early history of dissection. Sudhoff's Archiv fur die Geschichte der Medizin 1975;59:113–147.
12. Sigerist H. A history of medicine, vol. II. Early Greek, Hindu and Persian medicine. Oxford: Oxford University Press 1961.
13. Theophrastus. On the senses. In: Stratton GM, trans. Theophrastus and the Greek physiological psychology before Aristotle. London: Allen and Unwin 1917:67–151.
14. Freeman K. The pre-Socratic philosophers. Oxford: Blackwell 1954.
15. Grüsser O-J, Hagner M. On the history of deformation phosphenes and the idea of internal light generated in the eye for the purpose of vision. Doc Ophthalmol 1990;74:57–85.
16. Beare JI. Greek theories of elementary cognition from Alcmaeon to Aristotle. Oxford: Clarendon Press 1906.
17. Plato. Timaeus. Cornford FM, trans. New York: Bobbs-Merrill 1959.
18. Singer C. A short history of anatomy and physiology from the Greeks to Harvey. New York: Dover 1957.
19. Galen. On the usefulness of the parts of the body. May M, trans. Ithaca: Cornell University Press 1968.
20. Keele KD. Anatomies of pain. Oxford: Blackwell 1957.
21. Sigerist H. A history of medicine, vol I. Primitive and archaic medicine. Oxford: Oxford University Press 1951.
22. Zimmer HR. Hindu medicine. Baltimore: Johns Hopkins Press 1948.
23. Huang Ti nei ching su wên. The yellow emperor's classic of internal medicine. Veith I, trans. Baltimore: Williams & Wilkins 1949.
24. Porkert M. The theoretical foundations of Chinese medicine. Cambridge: MIT Press 1974.
25. Spence JD. The memory palace of Matteo Ricci. New York: Penguin 1985.
26. Lloyd GER. The Hippocratic question. Classical Quarterly 1978;28:202–222.
27. Hippocrates. On the sacred disease. In: Chadwick J, Mann WN, trans. The medical works of Hippocrates. Oxford: Blackwells 1950:179–189.
28. Edelstein L. The Hippocratic oath: Text, translation and interpretation. In: Temkin O, Temkin C, editors. Ancient medicine, selected papers of Ludwig Edelstein. Baltimore: Johns Hopkins Press 1943:3–63.
29. Clarke E, Stannard J. Aristotle on the anatomy of the brain. J Hist Med 1963;18:130–148.
30. Galen. On the doctrines of Hippocrates and Plato. DeLacy P, trans. Berlin: Akademie-Verlag 1978–84.
31. Lones TE. Aristotle's researches in natural science. London: London West Newman 1912.
32. Galen. On anatomical procedures, the later books. Duckworth WLH, trans. Cambridge: Cambridge University Press 1962.
33. Galen. On anatomical procedures, the surviving books. Singer C, trans. Oxford: Oxford University Press 1956.
34. Fraser PM. Ptolemaic Egypt. Oxford: Oxford University Press 1972.
35. Farrington B. Greek science, vol. II. Theophrastus to Galen. Harmondsworth: Penguin 1949.
36. Canfora L. The vanished library. Ryle M, trans. Berkeley: University Cal. Press 1990.
37. Von Staden H. Herophilus. The art of medicine in early Alexandria. Cambridge: Cambridge University Press 1989.
38. Dobson JF. Erasistratus. Proc Royal Soc Med 1926–7;20:825–32.
39. Longrigg J. Anatomy in Alexandria in the third century B.C. Br J His Sci 1988;21:455–488.
40. Pagel W. Medieval and Renaissance contributions to the knowledge of the brain and its functions. In: The history and philosophy of knowledge of the brain and its functions. Springfield: Charles C Thomas 1958:95–114.
41. Nemesius. On the nature of man. In: Telfer W, trans. Cyril of Jerusalem and Nemesius of Emesa. Philadephia: Westminster Press 1955:224–453.
42. Gross CG. Early history of neuroscience. In: Adelman G, editor. Encyclopedia of neuroscience, vol. 2. Boston: Birkhauser 1987:843–846.
43. Gross CG. The hippocampus minor and man's place in nature. Hippocampus 1993;3:403–415.
44. Edelstein L. The history of anatomy in antiquity. In: Temkin O, Temkin C, editors. Ancient medicine, selected papers of Ludwig Edelstein. Baltimore: Johns Hopkins Press 1943:247–301.
45. Clarke E. Aristotelian concepts of the form and functions of the brain. Bull Hist Med 1963;37:1–14.
46. Avicenna. The canon of medicine. Gruner OC, trans. London: Luzac and Co. 1930.
47. Schlomoh d'Arles GB. The gate of heaven. Bodenheimer FS, trans. Jerusalem: Kiryath Sepher 1953.
48. Burton RF, trans. The book of the thousand nights and a night, vol. 5. London: Privately printed by Burton Club, 1885.
49. Shakespeare W. The Merchant of Venice. 1600.