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Galen's Critique of Rationalist and Empiricist Anatomy

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> Beyond the first sensory impression, the powers of observation cannot penetrate the hidden nature of things without having recourse to preconceived ideas. For that reason, it would often be of more value in scientific accounts if the scientist, instead of claiming objectivity, would clearly indicate the "prejudice" that contributed to the advance into unknown territory.
>
> Adolf Portman[1]

Of all the sciences, none has a more empirical reputation than anatomy. Yet, this science's early history exemplifies a complex interplay between thinking and perceiving. The *Timaeus*, our oldest extant systematic account of the body's anatomical organization, uses many theoretical preconceptions. At the heart of Plato's descriptive accomplishment lies his account of how order can emerge from a marriage of mind and necessity.[2] Just a few years later, Aristotle describes even more of the body's details, after cutting open and manipulating organisms with the first recorded anatomical procedures. His level of sophistication ranges from preparing organisms for dissection so as to reveal the vessels' true relation with the heart, to cutting out the heart of a living turtle in order to discover the effect on its power of locomotion.[3] In

[1] Adolf Portman, *A Zoologist Looks at Humankind*, trans. J. Schaefer (New York: Columbia University Press, 1990), p. 37.

[2] For more on the importance of the *Timaeus* in the early history of anatomy see Christopher E. Cosans, "The Platonic Origins of Anatomy," *Perspect. Biog. Med., 38* (1995), pp. 581–596. The present paper is part of a larger inquiry into how anatomy began. Other papers from this study include, in addition to the paper just cited, Christopher E. Cosans, "The Experimental Foundation of Galen's Teleology," *Stud. Hist. Phil. Sci.* (forthcoming).

[3] In *Historia animalium*, Aristotle argues that in order to observe that all vessels originate from the heart, contrary tot the reports of Syennesis, Diogenes, and Polybus, one must first starve and then strangle the subject so that all vessels will still contain blood and be visible amidst the fat (*Aristotle: Historia animalium*, ed. and A. L. Peck [Cambridge, Mass.: Harvard

such procedures, theoretical understanding enables Aristotle to contrive the material manipulation necessary to create and observe special experience. Scientific reason thereby builds upon and extends the senses.[4]

In the next century at Hellenistic Alexandria, physicians apply experimental biology directly to man, and the philosophical conversation about reason and experience becomes a heated medical argument. While "Rationalist" physicians advance the anatomical method of Aristotle, they do not share his confidence in sense experience.[5] They seek to replace more phenomenological accounts about the body's organic nature with theories that reduce human life to mechanisms known only by extended chains of reason. Their particular style of thinking became known as *analogismos* (ἀναλογίσμος): a search that starts with something obvious and reasons to conclusions about more ultimate theoretical entities. With their emphasis upon invisible things revealed by science, the Rationalists take a more metaphysically aloof attitude toward the body.[6] In response, a second sect of physicians arose that rejects the Rationalists' confidence in the scientific theories supported by anatomical experiments: the Empiricists argue that medical procedures must instead be based upon practical experience of what works. Good physicians need neither answer nor even ask the question, "*What is* the body?"

Encountering the Rationalist-Empiricist argument after it has been going on for several centuries, Galen seeks a way out. Not happy with the choice offered by his contemporaries between theoretically aloof medicine and scientifically naive practice, Galen looks back to the classics of Hippocrates, Plato, and Aristotle for wisdom. He uses the terms "the Ancients" and "the Greeks" as almost synonymous with those who are brilliant and excellent. By addressing his work to timeless classics, Galen vaults himself beyond his particular "social and historical context." Rather than focusing upon the passing fashions of his day, his writing considers more universal and fundamental questions.[7] He refuses to commit himself as a member of any of the contemporary medical sects. This rejection of dogmatism makes Galen's epistemology difficult to classify in terms of his contemporaries.[8] He constantly stresses that the student physician must examine the body for himself. The best physician must both be acquainted with technical medical procedures, and be well versed in philosophical and scientific thought. By giving the student a hands-on intimacy with the body as well as a deeper theoretical understanding of its processes, experimental science can be an important part of a well-balanced education. While arguing that medicine should use the theoretical understanding yielded by anatomical experiments, Galen carefully confines himself within theory that is relevant to experience.

University Press, 1979], pp. 511b–515a). In *On Respiration*, he reports that "all blooded animals that are not very lively live a long time after the heart has been excised, for example tortoises even move be their feet if the shells are left on" (*Aristotle: On the Soul, Parva Naturalia, and On Breath*, ed. and trans. W. S. Hett [Cambridge, Mass.: Harvard University Press, 1975], p. 479a). Given the difficulty of removing enough shell to cut out the heart without disturbing the part of the plastron to which the legs attach, this procedure shows Aristotle as a quite sophisticated vivisectionist. (In order to ensure consistent terminology, all translations from Greek in this paper will be my own.)

[4] In *On coming-to-be and Passing-away*, Aristotle thus argues that all changing things, like organisms, are made up of the Hot-cold and Wet-Dry, which we perceive by touch (see the edition of H. H. Joachim [Oxford: Clarendon Press, 1922]).

[5] Many scholars of ancient medicine view "Rationalist" not as the name of a specific sect, but as a general term for a diverse group of physicians. I will use the term to refer to those physicians whom Galen calls Rationalists (λογικοί) or Dogmatists (δογματικοί). In addition to some of his contemporaries, Galen would also apply this term to the Hellenistic biologist Erasistratus, who shares much of the approach to the body that Galen characterizes as "Rationalist" in his works on sects.

[6] Mohan Matthen argues that "the Rationalists think that medicine is primarily concerned with reality not appearance," while the Empiricists hold that "medicine must take appearance to be its distinctive domain of investigation, not reality" ("Empiricism and Ontology in Ancient Medicine," in *Method, Medicine and Metaphysics* [Apeiron, 21:2], ed. R. J. Hankinson [Edmonton: Academic Printing and Publishing, 1988] p. 119). He concludes that the Rationalists would be more dogmatic about sticking with theoretically established treatments even if they appear not to work.

The Rationalists' Reductionistic Anatomy

Of the standard medical sects from Galen's time, the Rationalists are the only one to embrace anatomical experiments enthusiastically. Celsus reports that two of the Rationalist movement's heroes, Herophilus and Erasistratus,

> laid open men whilst alive – criminals received out of prison from the kings – and whilst these were still breathing, observed parts which beforehand nature had concealed, their position, colour, shape, size, arrange-

[7] Vivian Nutton, in "The Patient's Choice: A New Treatise by Galen," *Class. Quart., 40* (1990), 236–257, explains that Galen rejects the approaches of technical historians and etymologists, both of whom ignore the deeper meanings one can discover in classic texts. Instead of reading the Ancients to find out how things were, Galen studies them to learn how things are.

[8] Michael Frede, "On Galen's Epistemology," in *Galen: Problems and Prospects*, ed. V. Nutton (London: Wellcome Institute for the History of Medicine, 1981), pp. 65–86, argues that Galen is a Rationalist insofar as he embraces the rational method. Unlike the other Rationalists of his time, however, Galen believes that physicians and philosophers also need the empirical method to understand nature fully, and "if a theory does not accord with the phenomena, it is not the phenomena, but the theory which has to be rejected" (p. 82). I will argue below that Galen's stance involves a significant break with both his Rationalist and Empiricist contemporaries. In his account of anatomy, Galen ridicules Rationalists for their overly theoretical emphasis and rejects their effort at reducing life processes to mechanical abstractions. He advocates an experimental biology that gives greater weight to phenomenological experience and considers man's organic nature.

ment, hardness, softness, smoothness, relation, processes and depressions of each, and whether any part is inserted into or is received into another.[9]

In their experiments, Herophilus and Erasistratus thus treat human beings as experimental objects in order to learn "what is the body." They analyze man in terms of the objective qualities of his component parts, much as one would study the workings of a machine.

Although some scholars, like, Peter Dear,[10] have questioned whether experimental science began before the seventeenth century A.D., this view clearly overlooks the vast corpus of ancient science. While historians and philosophers of science offer numerous and sometimes arbitrary definitions of experiment, most scientists use the term to refer simply to theoretically sophisticated procedures that isolate specific phenomena in nature. In contrast to common observation, the experimenter creates special experience, which answers questions that arise from a particular theoretical understanding of the world.[11] Galen provides ample evidence that the Rationalists' manipulations were sophisticated enough to isolate phenomena that are not directly observable. He describes Erasistratus, for example, as exposing and tying off a large artery, inserting a long hollow tube below the ligation, binding the arterial wall tightly all around the tube, and then releasing the first ligature. Erasistratus claims that the resumption of the pulse distal to the tube indicates that the flow of pneuma hidden within the arteries causes the pulse by mechanically pushing against the arterial walls.[12]

[9] Celsus, *DeMedicina*, trans. W. G. Spencer (Cambridge, Mass.: Harvard University Press, 1935), pp. 23–24. Ludwig Edelstein, *Ancient Medicine*, ed. Owsei Temkin, trans. C. Lilian Temkin (Baltimore: Johns Hopkins University Press, 1987), pp. 247–301, exhaustively considers the reports of human dissection and vivisection in Hellenistic Alexandria. He persuasively argues that we should accept the nonpolemic reports, such as that of Celsus, at face value, and he offers a cultural explanation of why experimentation on humans might have occurred in Alexandria. Heinrich Von Staden, "The Discovery of the Body," *Yale J. Biog. Med., 65* (1992), 223–241, has more recently argued for acceptance of these reports, and has offered further analysis of the cultural factors involved.

[10] Peter R. Dear, "*Totius in verba*: Rhetoric and Authority in the Early Royal Society," *Isis, 76* (1985), 145–161.

[11] David C. Gooding, *Experiment and the Making of Meaning* (Dordrecht: Kluwer, 1990), provides rich philosophical analysis concerning the nature of experiments. In this paper, we see not only that the Greeks performed vivisection experiments, but also that a Rationalist-Empiricist discussion not unlike the one repeated in the seventeenth century helped ancient anatomists to develop an extremely sophisticated epistemology of experiments.

[12] See Galen, *Anatomical Procedures*, in *Galeni Opera Omnia*, vol. II, ed. C. G. Kühn (Hildesheim: Olms, 1965), II.648. I. Garofalo, *Anatomicarum administrationum* (Naples: E. J. Brill Lugduni Batavorum, 1986), has recently edited the Greek and Arabic text for the first four books of this work. Charles Singer, *Galen on Anatomical Procedures* (London: Oxford University Press, 1956), has provided an English translation of and commentary on the first nine books. For convenience of reference, I will cite the volume and page numbers form the Kühn edition of Galen wherever possible.

Although there are many factions of Rationalism in Galen's time, he characterizes them all as sharing an ideological commitment to mechanistic biology. This follows from their attempt to ground medicine on anatomical practice. In experiments one manipulates the body with instruments like scalpels in order to isolate and observe some aspect of the body. The experimenter's tools wrench the aspect out of the bodily context where it is normally concealed. In the first instance, this approach reveals a great deal about the body's tangible and geometric properties, for these are least altered by the biologist's disruption of the organism's natural dynamics.[13] Such inorganic aspects of the body become the core properties upon which the Rationalists build the rest of their conceptual framework. By applying reason only to this narrow core, they deduce a medicine focused on mechanism. In *On the Therapeutic Method*, Galen's own attempt to advance a system of medicine based on reason, he criticizes Rationalists for their narrow focus.[14] He claims that in following the teachings of Herophilus and Erasistratus some make "artery, veins and sinew[15] the principles" with which they understand the body.[16] Since these structures essentially go from one part of the body to another, they exemplify the importance of spatial arrangement to the body's nature. By applying *analogismos* to their observations of such gross structural features, the Rationalists extend their mechanistic narrative down to the microscopic level. Rather than explaining disease in terms of the proportions of the Hippocratic and Aristotelian Hot-Cold and Wet-Dry, many Rationalists consider the balances "in particles and passages."[17]

Galen portrays Erasistratus as especially keen to reduce human suffering and disease to abstract particles that move through theoretical vessels. Although none of Erasistratus's work is extant, we have modest evidence of his conceptual framework because Galen often refers to (i.e., attacks) him. Erasistratus believes that the arteries naturally contain pneuma, while the veins hold blood – presumably after seeing that the arteries of dead bodies are mostly empty. From the observation that progressively smaller and more numerous vessels branch off larger vessels, he infers that invisible branches

[13] For more on the geometric aspects of anatomical thought, see Cosans, "Platonic Organs of Anatomy" (above, n. 2).

[14] Galen, *On the Therapeutic Method*, in Kühn, *Galeni Opera Omnia*, vol. X. R. J. Hankinson, *Galen On the Therapeutic Method Books I and II* (Oxford: Clarendon Press, 1991), provides a translation of and commentary o this work's first two books.

[15] Although classicists often translate "*νευρά*" with its English cognate "nerve," this translation gives the Greek term unwarranted precision. Even in Galen's time some biologists used "*νευρά*" to refer not only to "nerves" but also to "ligaments" and "tendons."

[16] Galen, *Therapeutic Method* (above, n. 14), X.107. In his rich commentary, (above, n. 14) Hankinson suggests that this passage especially applies to Erasistratus, who argued that all bodily parts are composed form an interweaving of small arteries, veins, and sinews (p. 189).

[17] Galen, *Therapeutic Method* (above, n. 14), X.117.

continue to come off the system so that in the body "there is no existing place where a termination of a vessel does not lie."[18] Running between the terminals of the arteries and veins are theoretical connections called anastomoses (*συναναστομώσεις*).[19] Under normal circumstances the anastomoses are closed, thereby keeping blood and pneuma in their natural vessels. In the living organism, the veins deliver nourishment in the form of blood to the body from the liver. Arteries, on the other hand, provide the body with pneuma, which the heart draws from the lungs. The pulse results from the mass of pneuma that the heart thrusts out into the arterial system. Erasistratus's theory essentially offers a mechanistic explanation of the pulse, in which the arteries passively expand in response to the pneuma rather than actively vibrating from their own organic powers.

As a physician, Erasistratus is interested in discovering how the body works in order to better explain and treat pathological alterations of normal physiology. He especially tries to apply his vessel theory in the case of inflammation. Although constriction of the anastomoses usually keeps blood and pneuma in their proper vessels, in abnormal circumstances blood can enter the arteries. For example, if one cuts into the body, "through the wound all pneuma goes out and there is a danger that an empty place could form, so through the anastomoses blood follows filling up the position of the emptied pneuma."[20] Like Descartes, the great Rationalist and mechanistic biologist of the seventeenth century, Erasistratus abhors vacuums in his physiology: if a material leaves one part of the body, something else must be drawn in to replace it. Once inside the arteries, blood can cause all sorts of mischief. In general, Erasistratus believes that if too much blood "striking against and resisting pneuma changes its motion," a fever results.[21] In less extreme circumstances, the blood might simply block up the arteries, interfering with the pneuma's normal flow to the body and thereby swelling up the arteries. If enough arteries swell up, an inflammation results. Galen cites Erasistratus as holding that "an obstruction arises in the opening of arteries from necessity in inflamed parts."[22] Having reasoned out an account from experiments on

[18] Galen, *On Venesection Against Erasistratus*, in Kühn, *Galeni Opera Omnia* (above, n. 12), XI.153. Peter Brain, *Galen on Bloodletting* (Cambridge: Cambridge University Press, 1986), translates this and two other bloodletting works.

[19] Galen writes a great deal about anastomosis in *Whether Blood Is Naturally contained in the Arteries*, which has been edited and translated by David Furley and J. S. Willkie in *Galen on Respiration and the Arteries* (Princeton: Princeton University Press, 1984).

[20] Galen, *Against Erasistratus* (above, n. 18), XI.154.

[21] Ibid., pp. 155–156. I accept Brain's reading of *ἀλλοιοῦν τι* for the Kühn *ἀλλοιοῦντι* (*Galen on Bloodletting* [above, n. 18], p. 19); he notes that none of the manuscripts have spaces between words.

[22] Galen, *Therapeutic Method* (above, n. 14), X.119–120.

throbbing arteries, Erasistratus thus arrives at an explanation for how invisible things can cause the manifest condition of inflammation.

Armed with his theoretical beliefs about inflammation's true nature, Erasistratus applies his science to patients. Galen offers us a quote of Erasistratus' analysis:

> In unaffected places a communion between many opened arteries and veins arises [transferring] to these places (to the veins) the blood that had crept into the arteries. It then follows from these things to set no food before those wounded during the time of inflammation. For veins being empty of nourishment will receive easily the blood which had been transferred to the arteries. When this happens the inflammation will be less.[23]

In order to make room for the backflow of blood into the veins, Erasistratus holds that the patient must stop making new blood. The physician can facilitate this by ordering the patient not to eat. Having acquired a knowledge of the aspects of the body that are apparent neither from perception nor from the patient's bodily experience, the Rationalists link processes that one would not normally associate together. Scientific biology thus gives physicians a view of the body that differs from their patients' experience. Provided their theoretical analysis is correct, they can offer a brave new way of treating the body.

On a conceptual level, the Rationalist movement essentially uses anatomical biology to replace the patient's common experience of his body with a more aloof theory of bodily mechanisms. Since Aristotle uses the tangible qualities of Hot-Cold and Wet-Dry to account for the natural world, his science asserts the basic reality of perceptual phenomena and uses dissection and vivisection to build upon and extend the senses. The Rationalist biologists show that the scalpel cuts both ways by incorporating anatomical experiments into a conceptual framework that values reason over perception in the quest for scientific truth.[24] After beginning with the objective aspects of the body made manifest in manipulations, Rationalists reason their way to an account of the theoretical entities that cause the observed phenomenon. The Rationalists have such faith in reason that they favor their scientific version of

[23] Galen, *Against Erasistratus* (above, n. 18), XI.155–156.

[24] R. J. Hankinson, "Saying the Phenomena," *Phronesis*, *35* (1990), 194–215, uses Von Staden's collection of fragments to argue that Herophilus accepts theoretical entities but "wishes to emphasize, against any rampant rationalism, that everything has to start with the *φαινόμενα* [phenomena]" (p. 194). If true, this would make the historical Herophilus somewhat of an intermediary figure between Aristotle and the more reductionistic Erasistratus and Rationalists of Galen's time. It may also explain Galen's much more sympathetic attitude toward Herophilus.

things over their patients' internal perceptions. Galen reports that a follower of Erasistratus treating an inflammation cares "neither if it is unnaturally bulky, resistant, painful, or red, but only if an obstruction is in the openings of the arteries from a transfer."[25] While one's stomach might have a different opinion, scientific physiology teaches that in the case of inflammation, eating and recovering don't mix. Rationalist physicians thus place great weight upon their objective account of the body even if it conflicts with the patient's direct but subjective experience of his suffering.

The Empiricist Response

Although Rationalists performed dramatic experiments, their approach to medicine received mixed reviews. Of those skeptical about Rationalism, Galen takes none more seriously than the Empiricists.[26] He provides us with extensive and often sympathetic accounts of their epistemological and medical framework.[27] The Empiricists reject the Rationalists' theoretical confidence in knowledge concerning unmanifest entities and processes hidden within the living organism. They view the Rationalist attempt to base medicine on theories resulting from experimental biology as the greatest folly. The ultimate test for a treatment must not be whether it follows from "the body's true nature," but instead whether or not it helps patients recover. Experimental science simply cannot reveal the ultimate reality of things. Since the contrived mechanical interactions of experiments can only reveal the activities of the body in highly abnormal circumstances, they cannot uncover its natural state and reveal "what is the body."[28] Rather than cutting into and examining

[25] Galen, *Therapeutic Method* (above, n. 14), X.101.

[26] Galen dismisses out of hand the skepticism of the Methodist sect.

[27] Our two major sources of ancient Empiricism are Galen's treatises *On Medical Experience* and *An Outline of Empiricism*. In *On Medical Experience*, he attempts to reproduce the arguments typically used by Empiricists by presenting a debate in which a typical Rationalist attacks Empiricism, thereby setting the grounds for a lengthy defense of Empiricism by a typical Empiricist. It was one of Galen's first works, and was believed lost by him during his lifetime – yet a copy of it survived, and was translated from Greek into Syriac, and then from Syriac into Arabic. The original Greek of *Outline of Empiricism* was lost after a Latin translation of it was made by Nicolaus of Reggio in 1341. Since Nicolaus's translation technique was extremely literal, K. Deichgräber, *Die griechishe Empirikerschule* (Berlin: Weidmannsche Verlagsbuchhandlung, 1964), has attempted to reconstuct the Greek text from the Latin original. I will base all my translations on the Greek of Deichgräber's back-translation. Michael Grede, in Frede and R. Walzer, *Three Treatises on the Nature of Science* (Indianapolis: Hackett, 1985), pp. 21–45, provides a translation from the Latin, along with translations of *On Sects for Beginners* and *On Medical Experience*.

[28] Edelstein, *Ancient Medicine* (above, n. 9), pp. 195–203, provides a pointed analysis of how Empiricist skepticism toward Rationalist medicine ties into Hellenistic skepticism's rejection

cadavers, physicians can learn all they need about the body's structure by examining the wounds of living patients.

As an alternative to Rationalism, the Empiricists actively build and advance their own conceptual framework grounded upon perception.[29] They characterize "those things falling before the senses" as apparent (*φαίνεσθαι*).[30] In order for the fleeting appearances to make any lasting contribution to apprehension (*γνῶσις*), they must be retained by the memory. The Empiricists emphasize the importance of each individual's perception in their theory of technical knowledge. They dub the basic unit of learning a "personal-observation [*αὐτοψία*]." Although complaining about some confusion amongst the Empiricists, Galen defines personal-observation as "some memory of those things having been seen frequently in the same way."[31] In order to extend the scope of an individual physician's practice beyond his particular personal-observation, the Empiricists use "history [*ἱστορία*]" and "transition from similar [*τὴν τοῦ ὁμοίου μετάβασιν*]."[32] History consists of the accumulated record of other physicians' reports of their personal-observation. By studying such reports a young physician can acquire the wisdom from past generations on what diseases to look for and how to treat them. Even if confronted with a strictly novel affliction, the Empiricist might at least try a remedy that has worked in a similar condition. The physician can then report the success of this trial as a new personal-observation. According to Galen, most Empiricists use the term "experience [*ἐμπειρία*]" to refer to the totality of wisdom acquired by personal-observation, history, and similarity.

Because they reject the quest for a theoretical understanding of the body, the Empiricists have little more than a skin-deep commitment to experimentation. Although they "experiment" with the effects of treatments, they seriously question the relevance of invasive procedures such as dissec-

of the possibility of knowing things that are invisible by their very nature. R. J. Hankinson, "Causes and Empiricism," *Phronesis, 32* (1987), 329–348, gives a good account of the extent to which Empiricists shared much common ground with Pyrrhonist skepticism.

[29] Michael Frede, "The Empiricist Attitude towards Reason and Theory," in Hankinson, *Method, Medicine and Metaphysics* (above, n. 6), pp. 79–97, provides an extremely detailed account of the historical development of Empiricism.

[30] Galen, *Therapeutic Method* (above, n. 14), X.36.

[31] This passage is from *On Sects for Beginners*, in *Claudii Galeni Pergameni Scripta Minora*, vol. 3, ed. G. Helmreich (Leipzig, 1893), I.67. Galen complains both here and in his discussion of personal-observation in *Outline of Empiricism* (above, n. 27), p. 47, that some Empiricists also refer to the accumulation of apprehensions as experience. While personal-observation seems to exemplify what the Empiricists meant by experience, it seems from Galen's reports that the more sophisticated ones used experience in a wider sense.

[32] Galen, *On Sects*, I.67–68.

tion and vivisection.[33] Galen characterizes the Empiricists as "conceding neither that anatomical practice discovers anything, nor *even if it did* that this would be necessary to the art."[34] In *Anatomical Procedures*, he reports that some Empiricists actually write extended treatises against anatomical practice (ἀνατομή).[35] At the heart of the Empiricist rejection of anatomical experiments seems to be a strong faith in the power of clinical observation, as well as a skepticism toward the theoretical entities inferred from experiments. They admit that knowing about the position and shape of muscles, sinews, and vessels is useful to a physician, but argue that all of this can be learned from observing the open wounds of patients. The study of such cases focuses the student physician on just those aspects of anatomy he encounters in medical practice, and does not distract him with theoretical speculations about "the activities and usefulness of the parts."[36]

Galen provides us with a fascinating picture of the Empiricist approach to the body in the first book of *Anatomical Procedures*. When he was a student, his region of Asia was plagued by an epidemic that caused many patients to lose skin and flesh. He reports beginning Empiricist students as having "lifted and pushed aside many parts of exposed muscles, from which distress arose in the patients," while more advanced Empiricists were able to direct patients to make slight movements themselves.[37] By recording a history of past generations' personal-observations of wounds, the Empiricists could eventually catalog how all the body's parts might appear to the physician. If some aspect of the body cannot in principle be observed in such a context, then the Empiricists would dismiss it as irrelevant to clinical practice.

The Empiricist rejection of the Rationalist experimental program reveals anatomy as a theoretical science – its "empirical" reputation not withstanding. Twentieth-century biologists take the empirical nature of anatomical procedures for granted. In dissection the biologist simply looks at the body's structure, while vivisection allows the observation of its processes. In contrast to more imaginative enterprises like poetry, experimental biology relies upon the objective information of the senses to discover the true nature of life. Yet, cadavers do not come with labels included, and even simple dissections

[33] Von Staden, "Discovery of the Body" (above, n. 9), provides a detailed anaylsis of the Greek cultural attitudes toward the skin and why they led to a resistance to invasive anatomical procedures.

[34] Galen, *On Sects* (above, n. 31), I.77.

[35] Galen, *Anatomical Procedures*, Garofalo text (above, n. 12), II.288.

[36] Galen, *Therapeutic Method* (above, n. 14), X.100.

[37] Galen, *Anatomical Procedures*, Garofalo text (above, n. 12), II.225.

require the transcendence of experience with the theoretical imagination.[38] Medical students do not dissect cadavers to experience dead bodies, but to learn about the nature of the uninvaded living patients. Not surprisingly, when experimental biology made its first appearance more than two thousand years ago, it was not unanimously received as providing physicians with unadulterated truth. The application of experimental biology to man by the Rationalists put Western biology and medicine at an important crossroads. The Empiricist movement sought to insulate medicine from the theoretical approach to the body advanced by Plato and Aristotle.[39] Rather than losing his head in the clouds of theoretical speculation (or his hands in the bodily cavities), the physician must focus on what works.

Galen's Critical Anatomy

At the time that Galen began his education in the second century A.D., experimental biology was under siege. For the preceding four centuries Empiricists had fought a guerilla war against particular Rationalist efforts to theoretically justify treatments with dissection and vivisection. After being educated in both philosophy and medicine, Galen became the strongest advocate that experimental biology would have until the Renaissance. In his writings, he considers the insights of both sects, but ultimately rejects the choice between the theoretically aloof medicine offered by Rationalism and the anatomically naive practice advocated by Empiricism. Students of medicine should first master things that are useful to the practice of medicine, and then proceed to philosophical topics such as the nature of man.[40] Rigorous training in logic as well as hands-on experience with experimental biology allows the physician to rely upon the more theoretical areas of biology – not dogmatically, but critically.[41]

[38] I offer a case study on the extent to which theory and even values ground anatomy in Christopher E. Cosans, "Anatomy, Metaphysics, and Values: The Ape Brain Debate Reconsidered," *Biol. Phil.*, 9 (1994), 129–165.

[39] I explore Plato's contribution to the development of the anatomical approach to the body in "Platonic Anatomy" (above, n. 2).

[40] In the *Republic*, ed. and trans. P. Shorey (Cambridge, Mass.: Harvard University Press, 1935), pp. 519–540, Plato's Socrates likewise suggests that the guardians first be educated in practical matters before they are ready to study philosophy.

[41] Frede argues that Galen's critical attitude distinguishes him from the other eclectics of his time insofar as Galen (1) believes "it is one's own careful consideration of a matter, rather than the doctrine of a school or an authority which should determine one's views," and (2) "sees himself unable to take a position on a large umber of central philosophical questions, because he does not see how in the light of one's own reason and knowledge one could decide questions, e.g., concerning the nature of the soul" ("Galen's Epistemology" [above, n. 8], p.

Just like twentieth-century advocates of liberal education, Galen has tremendous admiration for the classics of his time. He often castigates the ignorance of his contemporaries while praising the wisdom of the Ancients or the "Greeks."[42] One should study the great thinkers of the past, not just to ascertain the nuances of their time, but also to recapture and learn their wisdom concerning the world in which we still live. Galen's list of great philosophers includes not only Plato and Aristotle, but also Speusippus, Xenocrates, Theophrastus, Zeno, and Chrysippus.[43] As a physician, he holds the greatest admiration of all for Hippocrates. He often invokes the name of Hippocrates to support his own positions, and writes many commentaries on Hippocratic texts.[44] By looking for the biomedical wisdom that preceded Hellenistic Alexandria, Galen recovers a patriarchal figure who might free medicine from the Rationalist-Empiricist quagmire. With his reverence for older learning, he seeks to seed a renaissance in an empirically realist experimental biology that considers the body's organic nature.[45]

In the anecdote of the Asian flesh-shedding epidemic discussed above, Galen criticizes the Empiricist approach to the body. While learning the human body's structure from wounds may seem reasonable in theory, it fails in practice. Since "memory of perceptible events requires constant inter-

71). J. Barnes, "Galen on Logic and Therapy," in *Galen's Method of Healing*, ed. F. Kudlien and R. Durling (New York: E. J. Brill, 1991), offers an exhaustive account of how Galen grounds medical practice on logic.

[42] At *Therapeutic Method* X.20, (above, n. 14) for example, Galen criticizes Thessalus, the founder of the Methodist sect, for breaking with the Greeks. Given Galen's own use of Greek as his native tongue and Methodism's origins in the Roman Empire, such a charge carries nationalistic connotations.

[43] Ibid., X.9. R. J. Hankinson, "Galen's Concept of Scientific Progress," in *Aufstieg und Niedergang der römischen Welt*, vol. 37.2, ed. W. Haase and H. Temporini (Berlin: Walter De Gruyter, 1994), pp. 1775–1789, provides an excellent anaylsis of how Galen tries to build upon the work of the Ancients.

[44] Nutton, "Patient's Choice" (above, n. 7), pp. 245–246, argues that admiration of the Hippocratic writings was by no means universal in Galen's time, and that the widespread respect these classics attained by the fifth century owes a great deal to Galen's advocacy.

[45] Unfortunately, Galen's seed did not fully take root until the translation of his experimental works into Latin and the assimilation of his anatomical methodology by such figures as Vesalius, some thirteen centuries later. Frede characterizes Galen's reverence for the classics as "a somewhat backward-looking rather than a forward-looking independence, which tends to choose from among the old rather than to create the new" (Frede and Walzer, *Three Treatises* [above, n. 27], p. xvii). Such a perspective shares an assumption common to many twentieth-century thinkers that truth values can be assigned to statements based upon their recency. Yet, the history of Western science has not been a unidirectional march toward truth. Charles Singer, *A Short History of Anatomy* (New York: Dover, 1957), pp. 62–65, points out that after Galen, biologists replaced experimentation with astrology as a way to study the nature of the body. Luckily for us, "backward-looking" physicians revived Galen's method in the Renaissance. Insofar as classics become classics by addressing timeless questions rather than the fashions of their day, they are often invaluable aids to the search for truth.

course [*ἡ γάρ τοι τῶν αἰσθητῶν πραγμάτων μνήμη συνεχοῦς ὁμιλίας δεῖται*]."[46] even a student studying many different wounds will have difficulty reconstructing the body's structural organization in his imagination.[47] Rather than seeing the same thing again and again, he encounters even the same parts in quite different situations. Yet, in order to make any sense of the chaos that the physician confronts in a wound, "it is necessary to see previously at much leisure each of the parts [*ὁρᾶσθαι γὰρ χρὴ πρότερον ἐπὶ πολλῆς σχολῆς ἕκαστον τῶν μορίων*]."[48] The details of the body are too numerous and wounds too sporadic to allow the student sufficient observation. Since Empiricists both begin and end anatomical studies with wound observations, young Empiricists must first learn how to see the body's order not only amongst its chaotic jumble of strands, goo, and blood, but also amongst the chaos of the clinic. Yet a new physician who pokes and prods someone's gashed-open arm is not likely to find his object of study very patient. True anatomical inquiry can occur only when the student is free from the patient's practical demands, in a time of leisure (*σχολή*).

Given the difficulties that today's students have in learning anatomy even with the aid of diagrams and preserved bodies, the extended verbal descriptions of Empiricist histories were probably not much help to the apprentices' first efforts at seeing anatomically. Not surprisingly, Galen describes young Empiricists observing their first wounds as "blind [*τυφλοὺς*]."[49] On this matter, he finds that a more theoretical approach to learning the body's structure is of immense practical use. The Rationalist approach of dissecting dead organisms enables the young physician to divide and conquer the chaos he first encounters in wounds. Galen reports himself and his colleagues, who had seen dissections of monkeys and other animals, as being able to see the structures within wounds without difficulty. They are even able to direct the patients to make specific movements in order to observe the actions of specific muscles! Galen explicitly recognizes the extent to which the observation of wounds can and must be theory-dependent: "those who had been previously shown something, solidified what they had studied, but those who had learned nothing previously were unable to learn everything."[50] However different a dead monkey may seem from a living human, the thorough study of one helps train the physician to make sense of the other.

[46] Galen, *Anatomical Procedures*, Garofalo text (above, n. 12), II.224.

[47] This criticism goes right to the heart of Empiricist epistemology. Frede, "Empiricist Attitude" (above, n. 29), pp. 87–88, notes that the Empiricists used "memory [*μνήμη*]" and other terms derived from it to refer to the processes by which one can properly connect experiences.

[48] Galen, *Anatomical Procedures*, Garofalo text (above, n. 12), II.224.

[49] Ibid.

[50] Ibid., II.225–226.

Although Galen begins medical training with more-theoretical experimental biology, he does accept a key Empiricist criticism of Rationalism: while theoretical studies can help the physician to successfully observe and manipulate the body, uncontrolled theoretical speculation can also distract him from practical things. As he sails into the waters of theoretical understanding, Galen is ever wary of the dangers presented by losing sight of experience. Even in his own account of theoretical medicine he cautions that "reason has not a little power to adorn or corrupt experience, but as much as good reasoning adds, so much or even more bad reasoning takes away."[51] While he recognizes a role for theory in medicine, he does not dismiss the merits of experience. If someone lacks the faculty to reason properly, Galen advises that he study medicine in the straightforward Empiricist fashion. In a significant concession to Empiricism, Galen recognizes the Empiricist approach to medicine as fully autonomous from theoretical considerations of invisible entities. Although he believes reason can help in the discovery of treatments, he has no problem using a treatment whose effectiveness has been shown empirically.[52] The improper or premature application of reason to experience is just as likely to detract from the more certain knowledge of experience as to enhance it. When an explorer sails off into unknown waters without good navigational equipment, even if he comes across land he will not know its significance and cannot indicate its location relative to anything he had previously known. Likewise, undisciplined reasoning can lead a young physician to many different accounts, with the only certainty being that not all of them are true.

When venturing into more-theoretical areas of biology, Galen keeps the biomedical enterprise on course with the compass of a sound intellect. In order to prepare for the critical consideration of Rationalist theories, he argues, the student physician must study not only medical treatments but also philosophy. Rather than learning medicine as a handicraft, the student should approach it as a liberal art. Such an education empowers the student not only with the empirical knowledge of what treatment might cure a particular disease, but also with an understanding of the world in which he must operate.[53]

[51] Galen, *Therapeutic Method* (above, n. 14), X.122–123.

[52] At *Therapeutic Method* X.123, Galen argues that one should study Empirical medicine in its entirety before attempting to synthesize it with the knowledge acquired through reason. In *On Sects for Beginners* (above, n. 31), I.74, he calls for a reconciliation of Rationalism and Empiricism through the acknowledgment that "both are true ways of discovery."

[53] Barnes, "Galen on Logic" (above, n. 41), pp. 93–102, argues that since many Greeks view physics as a branch of philosophy, Galen's exhortation that physicians should study philosophy involves physicians' being able to derive medical treatments form the principles of the basic sciences. In considering the problems faced by twentieth-century medicine, E. Pellegrino and D. Thomasma, *A Philosophical Basis of Medical Practice* (New York: Oxford University Press, 1981), think a liberal education is no less valuable for physicians today. They note that we need "the cultivation of the humanities and philosophy in the medical and health care setting with something like the vigor we dedicate to the basic sciences" (p. 37). Since medicine deals with man as both object and subject, it goes beyond scientific knowledge and "is also governed in its methodology by unique patient care needs that call for empirical-inductive thinking about individuals; intuitive, aesthetic, and rational forms of thought; history taking and dialogue; the pressure to decide; and an almost ancient respect for the search for causes, most often abandoned by modern science" (p. 93).

For Galen, the insight that a true physician must also be a philosopher is nothing less than divine revelation. After Galen began his education in philosophy, he reports, a dream told his father that Galen should "undertake to study medicine together with philosophy [*καὶ τὴν ἰατρικὴν ἐποίησεν ἀσκεῖν ἅμα τῇ φιλοσοφίᾳ*].[54] He thus began his own study of medicine as a supplement to a philosophical education. Having experienced the potency of this combination, he preaches its power to the entire medical world. In a small work aptly named *That the Best Physician is also a Philosopher*, he argues that in order to learn medicine well someone "would need all the parts of philosophy: the logical, the natural, and the ethical."[55] Logic helps the physician to use reason in a rigorous fashion, without getting lost among innumerable conflicting but equally reasonable accounts. A thorough training in logic ensures that he will be able to classify properly disease in kinds (*γένη*) and forms of kinds (*εἰδη*). Philosophy of nature teaches him the function of each part, as well as its composition. In deference to Rationalism, Galen believes that, if acquired and used rigorously, scientific knowledge can be of clinical relevance. Ethics teaches the young physician to value virtue more than material wealth, and frees him to pursue the virtuous ends of understanding the body and fighting disease. Interestingly enough, Aristotle argues in his ethics that the avoidance of excessive material desires liberates man to pursue the highest contemplative pleasures during leisure (*σχολή*),[56] which Galen sees as so important to anatomical study.

In calling for the philosophical education of physicians, Galen is ever wary of the theoretical extremes of the Rationalists. Instead of reducing the patient's experience to the motions of theoretical vessels and particles, Galen considers the body to be made ultimately of the Hot-Cold and Wet-Dry. He credits Hippocrates with grounding medicine on knowledge of the Hot-Cold and Wet-Dry, and Aristotle with giving this theory its first rigorous

[54] Galen, *concerning the Order of My Books for Eugenianos*, in *Claudii Galeni Pergameni Scripta Minora*, vol. 2, ed. Iwanis Mueller (Amsterdam: Adolf Hakkert, 1967), XIX.59.

[55] Galen, *That the Best Physician Is Also a Philosopher*, in ibid., I.60–61. Peter Brain, "Galen on the Ideal of the Physician," *So. Afr. Med. J.*, *52* (1977), 936–938, has published a translation of this work.

[56] See, for example, *Nicomachean Ethics*, ed. H. Rackham (Cambridge, Mass.: Harvard University Press, 1990), pp. 1177b–1178a.

demonstration.[57] Rather than advancing medicine, Galen sees the Rationalist effort to explain disease in terms of sinews, arteries, and veins as "bidding us to retreat from the height of nature study, and not to seek to learn the nature of the body as the philosophers learn by going as far as the first elements with reason."[58] Whereas Rationalists might use theoretical structures to replace or eliminate experienced entities, Galen grounds his approach to experimental biology on basic experience, just as does Aristotle. He fills his experimental manual *Anatomical Procedures* full of exhortations to the student to feel and see various parts for himself. Even when he advances intricate theories, Galen constantly stresses the importance of observed phenomena. He thus responds to Rationalism by reasserting empirical realism, after a period of experimental biology largely dominated by a version of theoretical reductionism. In reviving the Hippocratic and Aristotelian confidence toward basic perceptions, he uses experimentation to extend rather than replace the senses.

Galen does, however, preserve one insight of the Rationalists: experimental biology contributes to a well-rounded medical education. He sees the knowledge obtained from cutting open animals as important to four kinds of inquirers:

> There is use of anatomical inquiry for man as a naturalist who loves knowledge for itself; and also for him who loves it not for itself, but in order to show nothing occurs by nature in vain; and also for him who procures gratification from anatomical practice with the knowledge of some activity either natural or psychic; and also for him who intends to take or cut out or eliminate correctly stakes or splinters, and would be a little interested [in being able] to manipulate exactly bone, cavities, ducts, and abscesses.[59]

Given the slings and arrows of medical practice, the last use of anatomy has particular pertinence to the student physician. Galen admits that a physician

[57] Galen, *Therapeutic Method* (above, n. 14), X.16.

[58] Ibid., X.107. While Barnes, "Galen on Logic" (above, n.41), p. 98, interprets Galen as criticizing Rationalists for stopping short of first principles, it is possible that Galen views them as committing the even greater folly of using the wrong first principles. Insofar as sinews, arteries, and veins are structures connecting two points in the organism, the Rationalist grounding of anatomical explanations in invisible ones reduces the body to geometric abstractions. By contrast, Galen's use of the Hot- cold and Wet-Dry anchors his accounts of bodily activity in qualitative experience.

[59] Galen, *Anatomical Procedures*, Garofalo text (above, n. 12), II.286. Edelstein, *Ancient Medicine* (above, n. 9), pp. 264–265, argues that the first two kinds of inquiry refer to science, which studies anatomy for itself, and philosophy, which studies anatomy to prove teleology. However, this distinction imposes a twentieth-century dichotomy upon the text. Since Greeks considered the study of nature (φύσις) to be a branch of philosophy, they would regard all the activities of the sciences as philosophy.

can even use an understanding of inaccessible internal organs, like the liver, in diagnosing disease. Since the best physician is also a philosopher, the best medical student also studies experimental biology for the other three reasons. Just as do ethics and logic, the more theoretical aspects of experimental biology provide the student with a critical part of his basic education. Knowing about the body's purposive organization gives the student a deeper understanding of the world in which he operates. Such a student would ultimately be able to act in society not as a mere technician, but as a thoughtful scholar.

In order for theoretical biology to help the successful management of the human body, a physician must be ever wary of being distracted by issues too distant from the manipulable world. If one never senses or interacts with something, then long accounts of it are entirely irrelevant to medical practice. While Galen agrees with the Rationalists that anatomy and experimental biology have a place in biomedical education, he also shares the Empiricists' concern that young physicians study useful things first and foremost. Throughout *Anatomical Procedures*, he makes fun of Rationalists for devoting their attention to the more esoteric areas of anatomical knowledge, such as the nature of the heart and liver, while ignoring the clinically relevant anatomy. After noting how some physicians cripple patients by cutting across the muscle fibers, he ridicules them for "inquiring if some cartilage or bone lies in the pineal gland? and likewise if some piece of bone or cartilage exists in all hearts or just large ones?"[60] Theoretical contemplation can be an important part of a well-balanced education, but one must control his appetite. If a physician is ever going to apply his philosophical understanding to medicine, he must be able to maneuver around the less profound areas of the body. Even in Plato's *Republic*, philosophers must return to the cave, and administer the affairs of state.

Galen seeks to guide younger physicians properly by distinguishing between useful experimental biology, which constitutes the bread and butter of medical practice, from the nonpractical parts that serve as dessert for leisure time. The practical part of experimental biology provides the physician and philosopher with technical information useful to the practice of medicine. In order for a student physician to remove objects from the body without maiming his patient, he must learn the location and functions of its vessels, nerves, and muscles first and foremost. By knowing exactly which muscles flex and extend the knee, for example, the physician can cut into the thigh in a way

[60] Galen, *Anatomical Procedures*, Garofalo text (above, n. 12), II.419. I. Garofalo dubs this approach to the body " 'academical' anatomy" ("The Six Classes of Animals in Galen," in *Galeno: Obra, pensamiento e influencia*, ed. J. A. López Férez [Madrid: Universidad Nacional de Educación a Distancia, 1988], p. 85).

precise enough to preserve the basic motions necessary for walking.[61] Galen determines whether or not the knowledge of a part can help the practitioner by whether it lies amongst the body's interior parts (τὰ ἔνδον) or exterior ones (τὰ ἐκτὸς): the parts in the arms, legs, face, and exterior of the neck and trunk are more accessible to the physician, and must be known in the event of surgery.[62]

Galen "encourages" the young to first learn accessible anatomy by focusing exclusively upon practical anatomy in the *Anatomical Procedures*' first five books.[63] Before pondering the nature of the internal organs, the medical student must first learn the locations of the nerves, vessels, and muscles of the body's exterior. This practical anatomy can be best learned by frequent inspection of the bones of monkeys as well as dissection of their limbs and exterior. Galen recognizes that such topics are not the first things on the student's minds:

> I exhort the young, to leave alone for the present the dissections of the brain and heart, the tongue, lungs, liver[64] and spleen, kidneys, stomach, larynx, embryos and pregnant wombs, and instead to study how the arm, shoulder-blade and forearm are articulated, and how each of the other things about the limbs are: what muscles are moving them, and what nerves, arteries and veins lie in each of the parts.[65]

[61] For example, at *Anatomical Procedures* II.287–288 Galen notes that from observing the position of the gracilis and pulling on it in dissection, one can learn that it does not play an essential role in walking. In his account of the biceps femoris (II.298–299), he reports how an athlete who had torn and lost it was able to build up other muscles and eventually win races again.

[62] Since opening up the structure that twentieth-century biologists call the coelum would have caused massive infections in Galen's time of preantiseptic medicine, it makes sense that he considers the parts within it to be less accessible in the clinic. Interestingly enough, Galen has the student spend a tremendous amount of time peeling back the peritoneum, pleura, and pericardium from the body wall; such a procedure would help the student learn where *not* to cut in surgery.

[63] Once he has covered practical anatomy, Galen does reward the student's curiosity with more-theoretical experiments on the internal organs in the later books. See especially Galen, *On Anatomical Procedures, the Latter Books*, trans. W. Duckworth, ed. M. Lyons and B. Towers (Cambridge: Cambridge University Press, 1962). Garofalo argues that Galen originally planned to "confine himself to strictly medical anatomy" ("Six Classes of Animals" [above, n. 60], p. 85), but expanded the scope of this work during a twenty-year period of composition. However, Galen's latter treatment of theoretical anatomy does not abrogate his earlier account. In the first book of *Anatomical Procedures* he explicitly states that anatomical study can naturally progress from bones and muscles, to arteries, veins, and sinews, and finally to internal organs (Garofalo text, II.226).

[64] Since Greek biologists closely associate the liver and the spleen, I read ἥπατός with Kühn rather than Garofalo's ἧτατός.

[65] Galen, *Anatomical Procedures*, Kühn and Garofalo texts (above, n. 12), II.290.

Only after the student has mastered the less exciting but more practical anatomy does Galen reward him with a chance to open up the body cavity and see such parts as the liver and spleen. In studying the *Anatomical Procedures*, Mike Frampton and I followed Galen's directions on a *Macaca mulatta* monkey. After dissecting the outer structures of the monkey, Galen finally directs the student to open the abdominal cavity in book VI, but then asks him to spend hours pealing back the peritoneum from its wall – he thus "teases" the student with a focus on clinically important details before releasing him to proceed to the more alluring visceral organs.

Galen's approach to anatomy breaks both with Empiricists who studied parts only by observing them in a clinical context, and with Rationalists who began study by dissecting and vivisecting the internal organs. He thus advances a new perspective in which the physician need not choose between knowing how to maneuver the mundane pathways within the cave and knowing the brightest insights of the sun. Since Socrates describes the thoroughly educated philosopher's vision as "ten thousand times better,"[66] the best physician will know both.

In responding to the Rationalists and Empiricists of his time, Galen advocates a critical realism that both respects basic experience and seeks theoretical insight. On the one hand, he looks to science for a deeper understanding of the world than meets the eye. Theoretical understanding enables the scientist not simply to react to the world, but to manipulate it actively. If not overly indulged, philosophical understanding helps the physician to use this power responsibly. Knowing about the working of the heart, brain, or liver gives the physician an appreciation of his patient's organic nature. Yet if Galen rejects the Empiricists' vision of physicians as narrowly trained specialists, he also rejects the more extreme versions of theoretical reductionism endorsed by the Rationalists. Rather than reducing all the body's activities to mechanisms of invisible tubes and particles, he grounds his biology on parts that the scientist can directly manipulate in the laboratory. To learn about bodily structure, the biologist must dissect; to consider living activities, he must vivisect. In no case should the biologist base his beliefs upon what he reads that other people believe without experimenting upon organisms himself. Galen's infamous use of monkey dissection exhibits the careful balance he draws in responding to the two extreme epistemological systems: rather than dissecting monkey exteriors, Empiricists would look at patients' wounds, while Rationalists would rush to see the heart. Galen insists that the young physician must instead begin by learning the superficial nerves, vessels, and muscles of the monkey, because it gives him a scientific understanding of the phenomena that the physician must confront in his daily struggles to treat his patients. Galen

[66] Plato, *Republic* (above, n. 40), p. 520c.

views science as something not just to liberate the prisoner from the cave, but to enable him to help others upon his reentry.

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Converging Images: Techniques of Intervention and Forms of Representation of Sodium-Channel Proteins in Nerve Cell Membranes

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The principal focus of investigation in molecular neurobiology over the last two decades has been the characterization, manipulation, and representation of the molecules responsible for carrying and transmitting electrical information in the nervous system. The episode that I wish to examine here began with a series of papers in 1952 by A. F. Hodgkin and A. L. Huxley that hypothesized the existence of voltage- and time-dependent sodium and potassium "conductances" in the nerve cell membrane that could account for all the known properties of the action potential. They conceived of these conductances primarily in mathematical terms and represented them and the membrane with electrical circuits. In the early 1980s, principally as the result of the development of new techniques, two new representations of the sodium conductance emerged: bands of protein running on a polyacrylamide gel, and electrical traces of currents from the opening of single molecules. In the late 1980s, the gene coding for what was by now called the sodium channel was cloned and its sequence was determined, providing yet another form of representation. In each case, the scientists showed how the new representation could be transformed into the older, established representation to support their claim that the new representation was indeed of the sodium channel, and not of some other protein, or a loose resistor in the amplifier.

I also want to highlight the importance of the scientists' own mental images, by which I mean how they privately conceived of a large, complex, three-dimensional molecule moving in time and space.[1] While any two-dimensional representation on paper shows only one aspect of the channel, the conver-

[1] Although I am aware of the ongoing debate among cognitive scientists over experimental evidence for or against the existence of mental images, I am here concerned with historical evidence for their use by scientists in imaging molecules. For an overview of the debate see Michael Tye, *The Imagery Debate* (Cambridge, Mass.: MIT Bradford Press, 1991); and for an