Galen and the Squealing Pig

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Galen, who lived in the Roman Empire in the 2nd century, was the greatest experimental physiologist and anatomist of classical antiquity. His ideas about biology and medicine were dominant in Europe for more than 1500 years. In one of his most famous experiments, he demonstrated loss of vocalization after section of the recurrent laryngeal nerves in the pig. This may have been the first experimental evidence that the brain controls behavior and thought. NEUROSCIENTIST 4:216–221, 1998

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Galen was the most important figure in classical medical science, and he is our best source of information about it. He represents the peak of ancient Western Anatomia, physiology, and medicine. His ideas were so pervasive that the medieval world saw the structure and function of the human body through his eyes. Today, his extensive writings (Box 1) provide a vivid account of the context, controversies, and achievements of the 600 years of classical biology and medicine before his death in 199. After a brief account of Galen’s life and his contributions to neuroscience, we consider his most famous experiments on the nervous system, namely, the effect of cutting the recurrent laryngeal nerves. This demonstration, carried out with a squealing pig as subject, was famous in its own time and for centuries later. Although a long tradition before Galen held that the brain mediated sensation, cognition, and movement, the contrary view—that the heart served these functions—was dominant in Galen’s time. Galen’s experiments on the recurrent laryngeals were viewed as strong experimental evidence for the primacy of the brain in behavior and thought.

Galen’s Life

Galen (Fig. 1) was born to upper-class parents in 129 in Pergamon, a rich and ancient Greek city located on the site of the present-day Turkish city of Bergama, about 15 miles from the Ionian Sea. Pergamon was the traditional rival of Alexandria, and the rulers of Egypt had banned the export of papyrus to Pergamon to block the development of a rival library there. In response, the Pergamenes developed a new writing material made from animal skins called “charta pergamenam,” from which we derive the English word “parchment.” In Galen’s time, both cities were part of the Roman Empire, then at its peak (1, 6).

Pergamon was the site of one of the most famous Asclepieia, named after the Greek god of medicine, Asclepius. Asclepieia were combinations of medical treatment centers, healing temples, pilgrimage sites, and medical schools. A common therapeutic technique was to induce sleep with drugs (called incubation) and then to whisper in the sleeping patient’s ear that a particular treatment would be efficacious for his or her ills. The next day, when the patient was told the treatment plan by the doctor, the patient interpreted his or her dream as having foretold the doctor’s plans. The collection of buildings that made up the Pergamene Asclepium, along with monuments left by rich patients in recognition of their cures, can still be visited today (7–9). Pergamon was also the site of a major gladiatorial school.

Galen’s father, an intellectually inclined architect, began to tutor his son in philosophy and mathematics at an early age. When Galen was 16, however, his father had a dream, supposedly sent by Asclepius, that led Galen to begin the study of medicine. During his 4 years as a medical student in Pergamon, he published three medical texts, one on the uterus, one on the eye (now lost), and one on medical methodology. Over the next 8 years, he continued his medical studies at three other major medical centers, including Alexandria, the leading center of medical research and teaching. In this period, Galen acted more as a postdoctoral fellow than a medical student, carrying out research, writing on a variety of medical subjects, and maintaining his interest in philosophy. Finally, at the age of 28, Galen returned to Pergamon and was appointed physician to the gladiators, which provided him with a rich source of clinical and anatomical material, as most combats ended in serious or fatal injury (1, 6, 9).

In 161, a war between Pergamon and its neighbors caused the gladiatorial “games” to be closed, so Galen set off for the Rome of Marcus Aurelius (1). In Rome at this time, an unusually close relationship existed between the ruling politicians and aristocrats and the intelligentsia, particularly the philosophers and rhetoricians known as “Sophists” but also including other philosophers, physicians, and scientists. In this period, known as the “Second Sophistic,” the Empress Julia hosted a saloon of philosophers and writers, Greek intellectuals married Roman aristocrats, and the rulers of the empire sponsored and attended scientific demonstrations and lectures (9, 10).

In this unusual environment, Galen rose rapidly to the highest social and professional level of Roman society. Helped by curing several influential political figures, he built up a large and successful practice. One of his powerful patrons was Flavius Boethus, a former consul and later governor of Syria. Boethus encouraged Galen to compose his first major anatomical and physiological works. He also arranged for Galen to present a series of public anatomical demonstrations and lectures that were well attended by the intellectual and political elite. The most famous of these was Galen’s demonstration of the functions of the recurrent laryngeal nerve, discussed in detail later. During this period, Galen also became involved in several acrimonious disputes with other leading physicians (1, 6, 10, 11).

Perhaps because of these disputes or because of an epidemic in Rome, Galen returned to Pergamon. Soon after, the emperor, Marcus Aurelius and Lucius Verus, recalled Galen to accompany their troops in the field. He talked his way out of this assignment by becoming personal physician to Marcus’s son, Commodus. Galen continued to serve Commodus when he became Emperor and treated the subsequent emperor, Septimus Severus,
Box 1: Galen's Writings

Galen published voluminously on almost every branch of medical science and medical practice known in his time as well as his thoughts on philosophy, rhetoric, and his own life story (1). Most of Galen's works are lost; in the 1820s, the surviving Greek works were collected and translated into Latin by K. G. Kuhn. They make up 22 very large volumes. Some other works, which survived only in Arabic, have yet to be translated. Much of Galen's writing has not been translated into English, and most of the English translations were published only in the last few decades.

Galen discusses the circumstances surrounding his first public demonstration of the recurrent laryngeal nerves in On Prognosis (2). He also gives an account of the recurrent laryngeal nerves in On the Usefulness of Parts of the Body (3). The most detailed account, however, is in the later books of On Anatomical Procedures (4) (also known as De Anat. Admin.; Galen's works are most commonly denoted by abbreviations of their titles in Renaissance Latin).

A brief history of On Anatomical Procedures gives the flavor of the adventures of the ancient texts that managed to survive. It was originally a two-chapter work written in 169 BCE. Soon after, Galen's copies were lost in a fire and others were unavailable, so Galen eventually wrote a much expanded version in 177. Of this text, Books I–XI were published, but Books XII–XV were destroyed, along with many of his other works, in another fire and had to be rewritten. Only one manuscript copy survived in Western Europe, and it broke off in the middle of Book IX. It was first printed in 1525 by Aldus in Venice.

In 1844, the remaining books of On Anatomical Procedures were discovered as an Arabic manuscript in Oxford's Bodleian Library. They had been translated from Greek into Syriac by the great Arab physician Hunain ibn Ishaq (809–873) and then into Arabic by him and his nephew. The Bodleian Arabic manuscript was translated into German in 1906 and then into English in 1962 (4).

![Fig. 1. Portrait of Galen. From the Juliana Anicia manuscript, written in 487. Reproduced from ref. 5.](image)

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as well. Galen repeatedly boasted that as the result of his professional accomplishments, he became well known to all the leading philosophers and writers of his time as well as all the Emperors. He continued to treat patients, research, write, quarrel with other physicians, and be lionized in high society until his death in 199 (1, 6, 9, 10).

Model of the Physiological System

Galen believed that physiology and anatomy formed the critical bases of medical practice, and he wrote extensively on both subjects. His physiological system totally dominated physiology and medicine until William Harvey's work in the 16th century, and he remained very influential until the 19th century (3, 12).

In Galen's system, the fundamental principle of life was pneuma (akin to the chi of Chinese medicine and the vayu of Indian medicine). Pneuma entered the body from the all-pervading world spirit during breathing and passed to the lungs and then via the pulmonary vein to the left ventricle where it mixed with the blood. The blood had been made in the liver from chyle brought from the intestines by the portal vein. The liver had also given the blood the lowest type of pneuma, natural spirits, which were believed to be innate in all living tissue. The blood, with its natural spirits and nutritive material, was now distributed throughout the body by the veins in a tidal, or ebbing and flowing, motion. Some of the blood entered the right side of the heart, from which it had two possible routes. Most of the blood stayed in the right ventricle from which its impurities were carried off by the pulmonary artery to the lungs and exhaled. A smaller portion of it trickled into the left ventricle through the holes that Galen thought existed in the interventricular septum. There, it mixed with air that had come in from the lungs via the pulmonary vein and thereby became transformed into a higher type of pneuma, vital spirits. The vital spirits were distributed to the body and head via the blood in the arteries. Some blood carrying the vital spirits went to the base of the brain to the rete mirabile (a network of blood vessels at the base of the brain found only in the ox and some other animals but not in humans, although it was described and drawn as a very prominent feature of the human brain until Vesalius in the 17th century). Both here and in the choroid plexi inside of the ventricles, vital spirits were transformed into the highest pneuma, animal, or psychic, spirits. The brain ventricles were an important storage site for this psychic pneuma; from there it was distributed throughout the brain and via the (hollow) nerves to the rest of the body. This view of the physiology of the body remained dogma for over 1500 years (5, 12, 13).

Neuroscience Achievements

Whatever the weaknesses, from our perspective, in some of Galen's theoretical views, he made a number of major discoveries, particularly on the anatomy and physiology of the nervous system. He described in detail the course of 9, if not 10, of the cranial nerves (although he grouped them as seven pairs) as well as the sympathetic nerve trunks (4, 14, 15). He distinguished sensory and motor nerves for the first time and thought that this distinction derived from their source in the brain, a clear statement of Muller's Doctrine of Specific Nerve Energies. Galen's descriptions of the gross anatomy of the brain were very accurate, par-
particularly with respect to the ventricles and the cerebral circulation, both important in his physiological system. Galen usually presented his dissections as if they were of the human; but, in fact, they were invariably of animals, usually the ox in the case of brain anatomy, the bar- bary "ape" (the macaque *M. sylvana*) for cranial nerve anatomy, and pigs for vivisection. It was only in the second half of this century, when Galen's descriptions were evaluated in terms of the actual species dissected, that their great accuracy was realized (5, 15, 16).

Galen was the first to carry out systematic experiments on the effects of experimental lesions of the nervous system. Before him, no one had, as he put it, "ever taken the trouble to make a section themselves or put a ligature around parts in the living animal in order to learn which function is injured." He usually used a pig in these experiments "to avoid seeing the unpleasant expression of the ape when it is vivisected" (4, 13).

Galen realized that the spinal cord was an extension of the brain. In his brilliant and systematic experiments on sectioning the cord he compared the effects of hemi- and total transection at different levels; he noted that injuries interfered with sensory and motor function below the level of the section, that hemisection affected only one side, and that sagittal section did not produce paralysis. He accurately described the different roles of the spinal nerves in respiration (4, 13, 17, 18). Galen even came very close to formulating the Law of Spinal Roots:

The physicians do not even know that there is a special root at the origin of the nerves which are distributed to the entire hand and from which sensation arises; [nor do they know] that there is another root for the nerves moving the muscles (18).

Galen used piglets in his experiments on brain lesions. He found that anterior brain lesions had less deleterious effects than posterior ones (4). He viewed sensation as a central process because he knew from his clinical observations and animal experiments that sensation could be impeded by brain injury even when the sense organs were intact. Because animals could survive lesions that penetrated to the ventricles, Galen reasoned that the soul was not located there, but instead was located in the cerebral substance (19). He ridiculed the view of the Alexandrian anatomist, Erasistratus (290 B.C.E.), that intelligence was correlated with the number of cerebral convolutions, noting, "Even donkeys have a complex encephalon, whereas judging by their stupidity it [it] ought to be perfectly simple and uncomplicated" (3). This view continued to be cited in denigrating the role of the cerebral cortex well into the 18th century (20).

One way to measure Galen's achievements is to note how long it took for them to be superseded. His neuroanatomical discoveries were not surpassed until Vesalius in the 17th century, his studies of spinal transection not until Magendie in the 18th century, and his work on hemispheric function not until Gall in the 19th century.

**Brain and Heart**

The Hippocratic writers (4th century B.C.E.), particularly the author of *On the Sacred Disease*, had vigorously championed the hemispheric role of the brain in sensation, movement, and thought as Plato did (4th century B.C.E.). Indeed, this view had been held earlier by several of the pre-Socratic philosopher/physicians, starting with Alcmaeon of Croton (6th century B.C.E.). Furthermore, in the 2nd century B.C.E., the Alexandrian anatomists Herophilus and Erasistratus had explored in detail the structure of the brain and its role in sensation, movement, and menstruation in living animals and probably in living humans (20-22).

Yet 400 years later in the Rome of Galen's time, it was the common belief, even among leading physicians, that the heart rather than the brain was the central organ of sensation, movement, and memory. This had been Aristotle's view much earlier (4th century B.C.E.) and was a central tenet of the Stoic philosopher Chrysippus (280–207 B.C.E.), whose views continued to be highly influential, if not dominant, in Galen's time (19, 23). Indeed, Chrysippus's importance is indicated by the large amount of space Galen devotes to refuting his views in *On the Doctrines of Hippocrates and Plato* (19) and other works.

**Squealing Pig Demonstration**

Before coming to Rome, Galen had conducted extensive experiments on the nerves that control breathing. In the course of one of these experiments, carried out on a strapped-down pig as it struggled and squealed, Galen accidentally cut the recurrent laryngeal nerves that innervate the larynx. The pig stopped squealing but not struggling. After this incident, Galen traced out the course of the laryngeal nerves in detail in a variety of animals including long-necked birds. He accurately described how the nerves begin as a branch of the vagus (his "6th" cranial nerve), descend down far past the larynx, and then loop around the aorta on the left and the subclavian artery on the right before traveling back up toward the larynx (Fig. 2). He also confirmed that bilateral section of the laryngeal nerves in dogs, goats, sheep, and monkeys, and other animals as well as pigs eliminated vocalization. Furthermore, Galen mentions two instances of loss of vocalization in human infants after accidental injury to the recurrent laryngeals in the course of surgery to remove goiters (24).

In Rome, Galen's powerful patron, Boethus, arranged for him to conduct a public demonstration that section of the recurrent laryngeal nerves would eliminate vocalization (Fig. 3). Boethus rented the hall, obtained the requested pigs, and widely advertised the event. Many distinguished politicians and scholars came, including Alexander Damascenus, an Aristotelian philosopher. Before beginning the surgery, Galen gave a brief summary of the demonstration and noted that "there is a hairlike pair of nerves in the muscles of the larynx on both left and..."
right, which if ligated or cut render the animal speechless without damaging either its life or functional activity’ (2). At that point, Alexander Damascenus interrupted, objecting, ‘Even if we are shown that section of these nerves in animals renders them mute, it is not necessary to believe it true of human beings.’ In any case, he said, he would not believe such a demonstration. His insistent view reflected both a general skepticism of the value of sensory information as opposed to logic and geometry in establishing proof and the Aristotelian (and Stoic) belief that thinking and therefore vocalizing were controlled by the heart and not the brain (2, 23).

Galen later recorded his response to Alexander’s interruption:

When I heard this, I left them and went off, saying only that I was mistaken in not realizing that I was coming to meet boorish skeptics; otherwise I should not have come. ...On my departure, the others condemned Alexander.... When this was made known to all the intellectuals living in Rome...they all roundly reproached him and demanded that the dissections be performed in their presence when they assembled all others distinguished in medicine and philosophy. The meeting lasted several days, in which I showed them [the nerves controlling breathing] and how damage to the nerves activates the muscles of the larynx results in a loss of voice. My detractors were all put to confusion when I showed them this, and Boethus begged me to give him my lecture notes on it. He even sent trained shorthand writers to whom I dictated all my demonstration and argument (2).

From this shorthand came the treatise On the Voice, now lost but probably the basis of the section on the recurrent laryngeals in Galen’s On the Usefulness of the Parts of the Body (3), which is very much in the form of a public lecture.

Reasons for the Recurrent Course of the Laryngeal Nerves

Galen’s adoption of Aristotle’s biological teleology was consistent and relentless. Like Aristotle, Galen believed that everything in the body was designed in the best possible way for the best possible reason and that the perfection of this design demonstrated the existence and genius of the Creator. (Although he believed in a supreme being, Galen had so little interest in Christianity that he did not even distinguish it from Judaism [25].)

What, then, was the teleological reason for the tortuous route traveled by the laryngeal nerves down from the brain into the trunk and then around the aorta and subclavian arteries and back up to the laryngeal muscles? Before considering Galen’s answer, we must summarize his notions of muscular action. Galen thought that when a motor nerve enters the origin of the muscle it breaks up into small fibers and that the ligaments so do as well. At the insertion, these muscle and ligament fibers unite to form the tendon, which is then much stronger than if it had been made by the nerves alone. It is this tendon that contracts, he surmised, whereas the body of the muscle is mere “flesh” that protects the fibers (26). Because the pulling in muscle action is done by the tendon (made up in part by the nerve), the nerve must enter the muscle in the direction of the pull. This theory provided a rationale for the recurrent pathway of the laryngeals; they had to enter the larynx muscles from the bottom. In On the Usefulness of the Parts of the Body (3), Galen compares the passing of the nerves around the aorta and subclavian to a rope passed through a pulley. Apparently, pulley action was not well known to his audience so he explains it in reference to the “glossocomum,” a gadget for reducing fractures of the femur and tibia (Fig. 4), which was “a common device familiar to most physicians” that involved pulley action.

Now if the heart were the source of the nerves, as some think who know nothing of what is to be seen in dissection, it would readily move the [laryngeal] muscles by sending
large horizontal blood vessels as a ‘pulley or turning post.’ Galen’s description of the course of the laryngeal nerves is interrupted several times by exhortations to his audience to pay attention, praise of the Creator, and insults to rival anatomists, as in the following passage:

I want you now to pay me closer attention than you would if you were being initiated into the mysteries of Eleusis or Samothrace or some other sacred site…. You should consider that this mystery is in no way inferior to those and no less able to show forth the wisdom, foresight, and power of the Creator of animals, and in particular you should realize that I was the very first to discover this mystery which I now practice. Certainly, no other anatomist has known about any of these nerves or about the things of which I have spoken earlier in the construction of the larynx and this is the reason why they have erred so greatly in determining actions and have not told a tenth of the utilities of the parts. Accordingly, you must learn the things and follow closely my discourse as it explains the wonderful mysteries of Nature (3).

Fame of the Squealing Pig Experiment

Galen’s experiment on eliminating vocalization by cutting the recurrent laryngeal nerves has been heralded by one 20th-century student of Galen as “establishing for all time that the brain is the organ of thought and one of the most important additions to anatomy and physiology…the discovery of the circulation of the blood” (24). This and similar claims (3) are somewhat exaggerated and uninformative. As noted earlier, the idea of the brain as the organ of thought was clearly set out in many pre-Galenic writings, particularly in the Hippocratic treatise On the Sacred Disease and in Plato’s Timaeus. Even Galen, in his lengthy arguments against the Stoic philosopher Chrysippus, concentrates on experiments involving direct damage to the brain. It is true, however, that his demonstration on the pig was the first experimental and publicly repeatable evidence that the brain controls behavior. Previous evidence for the importance of the brain had been either exclusively clinical or based on indirect inferences from anatomy (20).

Galen’s demonstration on the squealing pig became one of the most famous single physiological demonstrations of all time. It inspired Leonardo da Vinci to produce a beautiful drawing of the recurrent laryngeal nerves (27). Vesalius gives it a prominent place (without mentioning Galen) in the last chapter of his great work, On the Fabric of the Human Body, and included it in his public lectures in Padua (28). Finally, Renaissance editions of Galen’s writings included in their frontispiece an illustration of Galen cutting the recurrent nerve in a huge pig (Fig. 3).

Persistence of Galenism

At about the time of Galen’s death in 199, classical science and medicine died. People preferred to believe rather than to discuss, critical faculty gave way to dogma, interest in this world declined in favor of the world to come, and worldly remedies were replaced by prayer and exorcism.

The world view of medieval Christendom found Galen’s teleology congenial to its own and, by smothering of critical facility, froze Galen and all biology into a sterile system for over 1500 years. Galen was not to blame. Rather than develop his discoveries and methods, the medieval world chose to accept his views as fixed and unchangeable fact in every branch of medicine.

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