Neurosurgery, as a subspecialty in general surgery, is a very recent development, having occurred only in the latter half of the 19th century. Three critical developments and concepts had to occur for neurosurgery to become a specialized subspecialty: anesthesia, antisepsis, and cerebral localization. All three of these developments occurred over less than 40 years (the 1840s to the 1870s). In this chapter, the underlying theme is that neurosurgery advanced as surgeons obtained a better understanding of the anatomy and pathophysiology of the nervous system, a goal that continues to be followed today.

This concept was clearly provided in 1602 by William Clowes, a leading surgeon of the Elizabethan age. Clowes invoked a challenge that neurosurgeons must still overcome, even in the age of computerized imaging, microsurgery, and functional neurosurgery:

Those which are Masters and Professors chosen to perform the like operation, ought indeede to have a Lyons heart, a Ladies hand, and a Haukes eye, for that it is a worke of no small importance.

Hippocrates, the father of medicine, had even further detailed this concept when he stated, “Nullum capitis vulnus contemnendum est”: no head injury should be considered trivial.

**NEUROSURGERY IN THE PREHISTORIC PERIOD**

Neurosurgery is, in many ways, one of the most ancient of professions. Early humans clearly recognized that to bring down an enemy, a blow to the head was the quickest means. To accomplish this goal, a number of weapons and, in particular, clubs were fashioned to inflict these injuries. Numerous anthropologic collections around the world include examples of skulls with head injuries; more remarkable are a number of skulls with successful trephinations: that is, the patient clearly survived the surgical incisions. Early humans clearly recognized that to bring down an enemy, a blow to the head was the quickest means. To accomplish this concept when he stated, “Nullum capitis vulnus contemnendum est”: no head injury should be considered trivial.

**ANCIENT EGYPTIAN NEUROSURGERY**

The earliest known written documents that relate to early neurosurgery date from the ancient Egyptian period. During this period, which covered approximately 30 successive dynasties, the earliest known practicing physician and Egyptian polymath lived: Imhotep, or li-em-Hotep (c. 2650–2600 BC). So powerful was Imhotep’s influence that he was given divine status after his death. This period of history has provided the earliest known existing medical and surgical writings. Three Egyptian papyri that have relevance to medicine still exist: the Ebers, Hearst, and Edwin Smith papyri.6-8 According to these Egyptian papyri, the practice of medicine was based largely on magic and superstition. Medical and surgical treatment relied on simple principles, whereby nature provided restoration of health with little intervention and mostly observation with simple mendicants. Of interest to modern neurosurgeons is the concept that the Egyptians realized that immobilization in a neck or back injury was important in reducing further injury. These early physicians commonly prescribed and applied splints for treatments.

The oldest medical text dates from this early civilization and was written in the 16th century BC, approximately 300 years after Hammurabi. This text, now called the *Ebers papyrus*, includes more than 100 pages of hieratic writing and is of interest for its extensive discussions of contemporary surgical practice. Included are discussions of the removal of tumors, along with recommendations for the surgical drainage of abscesses.6-8

The oldest work that deals extensively with medical and surgical techniques to deal with traumatic injuries is the *Edwin Smith papyrus*. Edwin Smith was from New York but had moved to Luxor, Egypt, to become an antiquities dealer; he acquired this papyrus in 1862. Smith spent considerable time translating the document into English. This didactic work appears to have been intended to be a surgical textbook. It was originally written during the time of the New Kingdom. This papyrus scroll is 15 feet in length and 1 foot in width and is written in a cursive hieratic script. The surviving text consists solely of a list of 48 cases, including 22 cases of injuries to the spine and cranium. There is even a case of a cranioplasty (Case 9), discussed along with what might be the earliest reported case of neurofibromatosis (Case 45). Each case is discussed with a diagnosis, followed by a formulated prognosis. As a result of scholarly research by Professor James Henry Breasted, this papyrus was translated again in 1930 from the original hieratic script. More recently (2012), a neurosurgeon (Gonzalo M. Sanchez) and a hieratic script expert (Edmund S. Meltzer) collaborated on reinterpreting the document and provided a more detailed medical/surgical explanation of the various cases. The papyrus is now in possession of the New York Academy of Medicine.6-10

The following two cases show the insight and some of the techniques illustrated in this early historical papyrus:

**Case Two**

**Title:** Instructions concerning a gaping wound in his head, penetrating to the bone.

**Examination:** If thou examinest a man having a gaping wound in his head, penetrating to the bone, thou shouldst lay thy hand upon it and thou shouldst palpate his wound. If thou findest his skull uninjured, not having a perforation in it, thou shouldst apply for him two strips of linen, and treat...
ABSTRACT

The field of neurosurgery is a very recent one, having developed only as a subspecialty at the end of the 19th century. The profession dates back to origin of Homo sapiens. Conflicts, falls, battles, and other events all have led to various forms of head injuries and trauma; people quickly realized that a blow to the head was the quickest way to bring down an enemy or an animal for food. Trephinations of the skull have been found in human skulls more than 10,000 years of age. This chapter is a review of neurosurgery dating to antiquity. In accordance with various schools of surgery and medicine, the development of neurosurgery is detailed from the writings of surgical experts and various schools of teaching around the world. Formal medical education begins with the Greek schools of the Asclepiads and Hippocrates. Greco-Roman surgeons such as Galen of Pergamon used the spoils of war and gladiators to learn human and animal anatomy and then the surgical skills to treat the surgical injuries. During the Byzantine era, the Islamic schools and Arab teachers codified much of the medical and surgical knowledge of antiquity. Although the medieval period in Europe led to the development of some strong and interesting surgical theories, few advances were made in dealing with head injuries. With the Renaissance came a better and more accurate understanding of human anatomy and, in particular, a better understanding of the brain and its underlying function. Modern experimental medicine and science began with the learned societies of Europe and some leading scientists and physicians. However, advancements in a field of surgery depended on three critical developments and concepts: anesthesia, antisepsis, and cerebral localization. No surgeon could operate on the brain without sufficient knowledge of the anatomic location of the lesion. The operation could be safely performed only with an anesthetized patient and good antisepsis. Before antiseptic techniques were developed, more than 85% of treated patients died of some type of sepsis. The 20th century led to the development of modern neurosurgery. With better instrumentation, diagnostic equipment, and superbly trained surgeons such as Harvey Cushing, the specialty of neurosurgery came into being. This chapter details the schools of teaching that led to the development of neurosurgery as a profession and the prominent individuals involved.
Historical Overview of Neurosurgery

The intellectual evolution of neurological surgery originated in the golden age of Greece with the founding of the Alexandrian School in 300 B.C. For the first time, open anatomic dissection was incorporated into formal lectures. The concept of a surgeon performing surgery on the head and spine also became formalized for the first time. Because of sporting injuries, particularly gladiator injuries, and wars, head injuries were clearly plentiful and provided ample opportunities to develop the early skills of neurosurgery.

The earliest medical writings from this period are those of Hippocrates (c. 460–370 B.C.), the most celebrated of the Asclepiadæ. Classical philologists consider that many of the writings attributed to Hippocrates were in reality composed by members of the Hippocratic School. The Hippocratic collection includes clinical cases based mainly on observation, and in most cases, only the simplest of theories are offered. The many neurological cases within the Hippocratic corpus reveal that the understanding of head injury was rather sophisticated. Hippocrates was the first to describe a number of neurological injuries, most resulting from battlefield injuries. The vulnerability of the brain to injury was categorized by location in the brain, from lesser to greater, with injury to the bregma being represented as a higher risk than one to the temporal region, which, in turn, was more dangerous than an injury to the occipital region. Hippocrates devoted a full chapter to injuries of the head, De capitis vulneribus, which deals with the diagnosis and management of head injuries and is the first systematic work devoted to head injuries. He divided head injuries into five categories that were based on the details of the skull fracture. Five types of fractures are described: linear fracture, contusion, depressed fracture, hedra (or dent) occurring with and without fracture, and contrecoup fracture. The neurological condition of the patient was not thought to have any bearing on the surgical indications. Surgery was advised according to the type of fracture. The greater the injury to the skull, the less was the need for trephination. The technical aspects of the process of trephination are presented in a curious mixture of sound advice and incomprehensible admonitions (Fig. 1-2).

The Hippocratic writings contain numerous anatomic descriptions, even though human dissection appears not to have been routinely practiced. The Greeks also were without an anatomic vocabulary, not to be introduced until Galen standardized the use of the Latin language in medicine. These deficiencies combined to limit any standardized anatomic procedures or the practice of surgery. Despite these drawbacks, the Hippocratic writings contain a number of interesting neurological case studies that reflect a view of the early practice of neurosurgery (Fig. 1-3).

One of the earliest descriptions of subarachnoid hemorrhage appears in the Aphorisms of Hippocrates and his followers also warned against incising the brain, as convulsions can occur on the opposite side and render the prognosis especially serious. Hippocrates advised against making an incision over the temporal artery, because this could also lead to contralateral convulsions. The writings of Hippocratic schools demonstrate the simple concepts of cerebral localization. Also well understood was the concept of a potential critical prognosis in head injury and that sometimes it was best not to operate. In this early era of medicine, the risk of infection, lack of antiseptic technique, and minimal anesthesia all precluded any serious or aggressive surgical intervention in head injury.

Herophilus of Chalcedon

From the region of the Bosporus, among the crowded schools of Alexandria, came Herophilus (Herophilus) (335–280 B.C.), a student of Praxagoras and Chrysippus and a member of the

Figure 1-1. A skull from Peru with a left frontal trephination accomplished by the “scraping” technique. The surgeon would use the two hand-held Peruvian tumins, positioned in front of the skull. These tumins, made of a copper/bronze mix, date from the period 800–1100 A.D. The patient survived the procedure, as indicated by evidence of healed bone regeneration at the site. (Courtesy James Tait Goodrich, MD, PhD.)

Gloss: As for: “Two strips of linen,” it means two bands of linen which one applies upon the two lips of the gaping wound in order to cause that one join to the other.

Title: Instructions concerning a gaping wound in his head, smashing his skull.

Examination: If thou examinest a man having a gaping wound in his head, penetrating to the bone, and smashing his skull; thou shouldst palpate his wound. Shouldst thou find that smash which is in his skull deep and sunken under thy fingers, while the swelling which is over it protrudes, he discharges blood from both his nostrils and both his ears, and he suffers with stiffness in his neck, so that he is unable to look at his two shoulders and his breast…

Diagnosis: Thou shouldst say regarding him: “One having a gaping wound in his head, penetrating to the bone, and smashing his skull, while he suffers with stiffness in his neck. An ailment not to be treated.”

Treatment: Thou shalt not bind him but moor him at his mooring stakes, until the period of his injury passes by….

Other than the isolated cases, these remaining papyri provide little information about the actual practice of neurosurgery. It is evident from these writings that Egyptian physicians recognized head injury and would elevate a skull fracture if necessary. At the same time, if the injury appeared to be too severe, then no treatment was advocated. Both the management and the codification of head injury were not formalized until the development of the Greek schools of medicine (c. 460 B.C.), by individuals such as Hippocrates.

CLASSICAL PERIOD: GREEK AND BYZANTINE NEUROSURGERY

Hippocratic School

The intellectual evolution of neurological surgery originated in the golden age of Greece with the founding of the Alexandrian
neurological contributions included following the origin of nerves to the spinal cord anatomically. He was the first to recognize the difference in the motor and sensory tracts. Furthermore, he differentiated between nerves and tendons, thereby correcting a common earlier error. Herophilus was first to detail the anatomy of the brain ventricles and venous sinuses. The description of the “confluence of the sinuses,” or torcular herophili (Λανζζε = wine press), comes from his early investigations. Herophilus provided the first description and naming of the choroid plexus (plexus choroides), so named because of its resemblance to the vascular membrane (chorion) of the fetus. Herophilus also provided the first detailed account of the fourth ventricle and that peculiar arrangement at its base that he called the calamus scriptorius (Αναγλυφη τχ χαλαµχ), which he described as “resembles a pen in writing.” Among his many other contributions was his recognition of the brain as the central organ of the nervous system and the seat of intelligence.20

Herophilus’s writings were not free of errors. An anatomic error that remained in vogue for nearly 1800 years was his introduction into the anatomic literature of the rete mirabile, a structure present in ungulates but notably lacking in higher primates. In ungulates this structure acts as an anastomotic network at the base of the brain, a structure that the Greeks incorporated into the early physiologic theories of brain function.21 In the 2nd century AD, the rete mirabile was later further detailed and elaborated on by Galen of Pergamon. The concept of this structure became entrenched in the anatomic literature, having been codified by the Byzantine Islamic and later European medieval writers, until the 16th century, when it was finally challenged in the anatomic accounts of Andreas Vesalius (1514-1564) and Jacopo Berengario da Carpi (1460-1530).23-25 Both of these anatomists, who performed their own human dissections, clearly recognized that the rete mirabile did not exist in humans. It is possible that the human cavernous sinus confused the early writers and they in turn thought that this represented the rete mirabile.

**Aulus Aurelius Cornelius Celsus**

Celsus (25 BC-50 AD) was neither a physician nor a surgeon, nor was he a bedside practitioner; rather, he was an intellectual patrician and a medical encyclopedist who attempted to compile all of the important writings of his time. His writings had an important early influence on medicine and surgery. His medical writings were mostly a compilation of the writings from the schools
of Hippocrates and the Asclepiadæ and from the Alexandrian schools. Celsus lived during the height of the Roman Empire. As counselor to the emperors Tiberius Caesar and Caligula, Celsus was held in great esteem. His book on medicine, titled De Re Medicina,26,27 is now considered one of the most important early medical documents after the Hippocratic writings. Because this work was originally lost, Celsus was one of the few major authors whose works were not transcribed by the Islamic/Arabic writers. In 1443, an early Celsus manuscript was uncovered by Thomas of Sarzanne (later Pope Nicolas V) and reintroduced to the medical community. With the introduction of printing and moveable type, Celsus’s manuscript became the first medical writing to be printed (1478), before even the writings of Hippocrates and Galen. In the De Re Medicina, Book IV, Chapter 10, his classic description of inflammation appears: “Notae vero inflammationes sunt quattuor, rubor, et tumor, cum calore et dolore [There are four signs of an inflammation: redness, swelling, heat, and pain].”

Celsus made a number of interesting early observations in the field of neurosurgery. Celsus believed that all surgeons should be ambidextrous. Book VIII, Chapter 4, contains one of the earliest descriptions of an epidural hematoma resulting from a ruptured middle meningeal artery.27 For head-injured patients, Celsus recommended that the surgeon always operate on the side of greater pain. Celsus was a strong advocate for use of the trephine in head injuries. He noted that the trephine should always be placed at the point where the pain is best localized. Celsus described a technique for a craniectomy that involved drilling a number of holes and then connecting them with a hammer and chisel. The chisel had a protective blade, which separated the dura from the bone and prevented injury to it during the surgical dissection. However, he regarded the operation of trephination as the ultimum refugium, to be used only when all conservative measures had been exhausted (Fig. 1-4).

Several interesting neurological conditions are described in the De Re Medicina, including accurate descriptions of hydrocephalus and facial neuralgia. In accordance with earlier writings, Celsus clearly recognized that a high cervical spine fracture could lead to vomiting and difficulty in breathing. Injury to the lower lumbar spine could cause weakness or paralysis of the legs, as well as urinary retention or incontinence.

**Galen of Pergamon**

Galen of Pergamon (129–200 AD), whose name comes from galeno, meaning “calm” or “serene,” is remembered as a powerful personality and an original investigator, as well as a leading proponent of the doctrines of Hippocrates and the Alexandrian school. Galen began his writing career at the age of 13 and continued to add to the literature of medicine, philosophy, mathematics, and grammar until his death at the age of 70. His writings remained the most extensive in early antiquity in size, scope, and influence. Galen’s prodigious output still accounts for more than 80% of all the surviving medical writings of antiquity.28 Many of his writings and manuscripts, however, were lost in a fire at the Temple of Peace in Rome (Figs. 1-5 and 1-6).

Galen’s life and activity occurred during the reigns of two of the greatest Roman emperors: Antoninus Pius (86–161 AD; reigned 138–161 AD) and Marcus Aurelius (121–180 AD; reigned 161–180 AD). Galen became the physician to the gladiators of Pergamon and, as a result, saw and treated many traumatic injuries. Drawing from both his surgical experiences and anatomic studies, he made a number of contributions to the fields of neurology, neurosurgery, and neuroanatomy. In his writings, Galen differentiated between the pia mater and the dura mater and gave one of the earliest accurate descriptions of the corpus callosum, the ventricular system, the pineal and pituitary glands, the infundibulum, and what is now called the aqueduct of Sylvius.

Nearly 1600 years before the Scottish anatomist Alexander Monro secundus (1733–1817), Galen also described the structure now called the foramen of Monro. He performed a number of anatomic experiments, including early studies on the effects of transection of the spinal cord.29,30 From these studies, Galen was able to describe the specific loss of function below the level of transection. In a now classic experiment, he sectioned the recurrent laryngeal nerve in dogs and described the hoarseness

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**Figure 1-4.** A, Portrait of Celsus. B, Title page from a 1542 edition of Celsus’s writings. (Courtesy James Tait Goodrich, MD, PhD.)
that occurred (discussed further in Chapter 7; see also De usu partium corporis humani, Book VII, Chapters 11-18).

Galen was the first to provide an early classification of the cranial nerves. In his original classification, he described 11 of the 12 cranial nerves, but because he combined several, he thought the total was only 7. In his descriptions, Galen regarded the olfactory nerve as merely a prolongation of the brain and hence did not consider it as a cranial nerve. Galen published a number of interesting views on higher cortical functions, embracing views that the brain was responsible for intelligence, fantasy, memory, and judgment. In studying muscle contractions, Galen made the observation that the stimulus originated in the brain and the impulse was carried to the muscle by nerves. These views were original and represented an important departure from the cardiocentric teachings of the earlier medical and philosophical schools such as Aristotle’s. Galen challenged the Hippocratic view that the brain was only a gland and instead attributed to the brain the powers of voluntary action and sensation (encephalocentric), this last being a remarkable advance in thinking for the period.

From a series of anatomic studies, Galen provided some of the earliest observations on cervical spine injury and the resulting disturbance in arm function. Further study of spinal cord injury led to his elegant description of what is now called the Brown-Séquard syndrome, a hemiplegia with contralateral sensory loss that results from a hemisection of the cord. Galen provided one of the earliest clinical descriptions of hydrocephalus and clearly recognized the poor prognosis in affected individuals. Using his extensive experience in head injuries, he provided some innovative arguments for elevation of depressed skull fractures, fractures with hematomas, and comminuted fractures. Galen was more aggressive in his treatment by recommending the removal of bone fragments, particularly those pressing into the brain. In describing surgical techniques, Galen detailed a safer and more reliable use of the trephine and argued particularly for continuous irrigation to a trephine to avoid delivering excessive heat and causing injury to the underlying brain. Galen, following or adapting earlier Hippocratic views, reiterated the concept that the dura should never be violated by the trephine. Each of these errors or incorrect beliefs were carefully repeated and scribed by subsequent Arabic/Islamic and medieval
historical overview of neurosurgery

To have been the first to suggest the possibility that an intraventricular hemorrhage and its “inert fluid” might actually cause hydrocephalus:

The hydrocephalic affection...occurs in infants, owing to their heads being improperly squeezed by midwives during parturition, or from some other obscure cause; or from the rupture of a vessel or vessels, and the extravasated blood being converted into an inert fluid....

(Book VI, Section 3, page 250)32

One of the reasons for Paulus’s longstanding influence was that several of his manuscripts survived and were continuously recopied by amanuenses over the centuries. These manuscripts depict a number of surgical instruments that he designed specifically for neurosurgical procedures; these include elevators, rasptories, and bone biters. He also introduced trephine bits with conical styles to reduce the risk of plunging, along with different biting edges. Because of his sophisticated wound management, he probably had better-than-average surgical outcomes. He made use of wine-soaked dressings (helpful in antisepsis, although a concept then unknown), and he stressed that dressings should be applied with no compression to the brain itself.

The Greek and Byzantine periods were eras of intense scholarship and original investigation in medicine and surgery and produced physicians and surgeons who were intensely interested in the better management of their patients. As discussed, individuals such as Galen of Pergamon, Paulus Aegineta, Herophilus of Chalcedon, and members of the Hippocratic school all attempted to improve management in head injuries and at the same time uncover some of the principles of brain function. Unfortunately, as discussed in the next section, further neurological investigation and the development of new surgical techniques were seriously impaired because of scholarly reverence of these earlier writers. Although there were some exceptions to this trend, they were distinctly uncommon.

Paulus Aegineta (Paul of Aegina)

Paulus Aegineta (625-c. 6) was a brilliant Byzantine Greek physician and surgeon who also trained in the Alexandrian school. He was an influential compiler of works in both the Latin and Greek schools; his writings, especially The Seven Books of Paul of Aegineta, were being consulted until well into the 17th century; the Compendium was translated into English in the 19th century. His skill as a surgeon, described in the sixth book of the Compendium, clearly reflected an unusual understanding of surgical principles. His skills became legendary, causing patients from far away to consult him. Although Paulus venerated the teachings of the ancients as tradition required, he also introduced his own techniques with good results. His classic work, The Seven Books of Paul of Aegineta, contains an excellent section on head injury and the use of the trephine.31,32 Paulus classified skull fractures in several categories: fissure, incision, expression, depression, arched fracture, and, in infants, dent (what is now called a ping pong fracture). In dealing with fractures, he used an interesting skin incision: two incisions intersecting one another at right angles, forming the Greek letter X, one leg of the X incorporating the scalp wound. For the comfort of the patient undergoing a trephination, he would stuff the patient’s ear with wool so that the noise of the trephine would not cause undue distress (see The Seven Books of Paul of Aegineta, Book VI, Section XC).32 (Fig. 1-7).

In a contemporary discussion on hydrocephalus, Paul of Aegina introduced the intriguing concept that traumatic birth delivery and intraventricular hemorrhage were related; he appears to have been the first to suggest the possibility that an intraventricular hemorrhage and its “inert fluid” might actually cause hydrocephalus:

The hydrocephalic affection...occurs in infants, owing to their heads being improperly squeezed by midwives during parturition, or from some other obscure cause; or from the rupture of a vessel or vessels, and the extravasated blood being converted into an inert fluid....

(Book VI, Section 3, page 250)

Figure 1-7. A, Portrait of Paulus Aegineta. B, Title page of the collected works of Paulus Aegineta. (Courtesy James Tait Goodrich, MD, PhD.)
After the great Greek and Roman periods of medicine, the intellectual centers of this discipline shifted to the Islamic/Arabic and Byzantine cultures. This era, “The Golden Age of Islamic Medicine,” had an influence that lasted from approximately AD 750 until 1200, when the medievalist era began and the influential schools of medicine shifted to Europe. Interestingly, this period in Europe was intellectually quiescent and unimaginative because this area of the world had been overrun and ruled by barbarians (Huns, Goths, and Norsemen), individuals not concerned with high scholarship. Unfortunately for neurosurgery, this was a dormant period; the dormancy prevailed in all facets of surgery. The Islamic/Arabic schools were satisfied to codify the surviving manuscripts from the Greek and Roman period. Remarkable insights were offered, but this was a rather rare phenomenon. However, thanks to the zeal of the Arabic amanuenses, the best manuscripts from the Greek and Roman period. Remarkable insights were offered, but this was a rather rare phenomenon. However, thanks to the zeal of the Arabic amanuenses, the best of Greek medicine was made available to Arabic readers by the end of the ninth century and remained available into the Middle Ages.

Unfortunately, a rigid scholastic dogmatism became characteristic of these learning centers. Rather than offering innovation, the “writers” became copyists of the great works of antiquities. As a result of their efforts, an amazing number of manuscripts were translated from Latin, Greek, and Hebrew into Arabic, and knowledge that could have been easily lost into antiquity was systemized. Unfortunately, as copyists, these writers frequently added their own “favorite” or contemporary view of the manuscript, and some of the originality was consequently lost in translation. In fairness to these early copyists, they rendered the service of preserving knowledge; in Europe at this time, having been overrun by barbarians, scholarly pursuit remained at a standstill.

A number of modern writers have offered the view that it was the religious influence of the Koran that caused the absence of originality and progress in Islamic/Arabic medicine. It has often been commented on that the Koran forbade dissection; this is only partially correct. Some dissection was allowed and reported on by writers of this time. However, as a practical consideration, the climate in this part of the world was hot, which caused rapid putrefaction of cadavers and made anatomic dissection undesirable. The opinion of these schools was that the Greeks had already accomplished most of the anatomic studies of interest, and so Islamic students of medicine felt no need to duplicate these earlier and more superior efforts. There were some rare exceptions that are discussed as follows.

In Islamic/Arabic medicine, the concept of a physician doubling as a surgeon was rarely acceptable. The more typical practice for a physician was to confine himself to writing learnedly and assign the “menial” tasks of surgery to an individual of a lower class, most typically an apprentice surgeon. As a result of this “demotion” of the surgeon to a mere plebeian, the advances in surgery and anatomy developed by the great Alexandrians, among others, were essentially ignored or lost. Fortunately, the writings of physicians such as Galen of Pergamon and Paulus Aegineta were saved and translated into Arabic, but few new techniques or concepts were added.

The dominant period for Islamic scholarship in medicine was the 10th through 12th centuries. Several medical scholars rose to prominence during this period; among the most illustrious were Avicenna (980–1037), Rhazes (865–925), Avenzoar (d. 1162), Albucasis (1013–1106), and Averroës (1126–1198). The writings of these great physicians reveal an extraordinary effort to canonize the writings of their Greek and Roman predecessors. Rather than innovation, these Islamic/Arab scholars and physicians became the guardians and academicians of Hippocratic, Greek, and Galenic writings, which now became dogma.

One of the most beneficial teaching methods, and quite modern, did arise during the Islamic/Arabic period: the concept of bedside medical care and teaching. The relative paucity or lack of regular anatomic dissection, along with the prevalent view that surgery was performed only by individuals of inferior status, inevitably reduced any preoccupation with surgical art. Another unfortunate surgical practice that occurred during this period was the reintroduction of the Egyptian technique of using the hot cautery for control of bleeding. In addition, hot cautery was also employed in lieu of the scalpel to create a surgical incision, the results of which often proved unfortunate for surgical patients (Fig. 1-8).

One of the significant scholars of this period was Rhazes (Abu Bakr Muhammad Ibn Zakariya) (865–925). Rhazes was a scholarly physician, learned in diagnosis, and a review of his writings reveals him to be loyal exclusively to Hippocratic teachings. Rhazes developed a considerable reputation that led him to become a court physician. Rhazes was not a surgeon, although he did write on surgical topics. Rhazes introduced the use of animal gut as a suture material. Rhazes was an early believer in the concept of “concussion” and would advocate surgery for penetrating injuries of the skull—this in a period when these types of surgical outcomes were almost always fatal. Rhazes believed that head injuries were among the most devastating of all injuries. Because skull fractures could be permanently damaging to the patient as a result of the compression of the brain, his surgical advice would be to elevate these depressed areas of the fractured skull.

Among the most influential physicians of this period was Avicenna (980–1037), physician and philosopher of Baghdad, also known as the chief or “second doctor,” the first being Aristotle. Avicenna’s writings and translations clearly extended the original Greek influence with a force so persuasive and durable that it remained the dominant scholarship until well into the 18th century. His greatest contribution must be judged to have been the detailed translation of Galen’s collected works, the Opera Omnia. Avicenna’s major work, Canon Medicinae, was an encyclopedic effort clearly based on the writings of Galen and Hippocrates. The Greek word canon refers to a straight rod, a carpenter rule, or standard of measurement. Accordingly, Avicenna’s Canon became the “rule,” the codification of Galen’s and Greek medicine. The Canon contains a number of interesting neurological discussions. Avicenna provided an early and accurate clinical understanding of epilepsy, for which his treatment consisted of administering various medicaments and herbs with described good results. Avicenna apparently conducted anatomic studies, although he did not discuss this directly. He gave a correct anatomic commentary on the vermis of the cerebellum.
made so little progress in surgery. Albucasis attributed this lack of progress to a lack of anatomic study and inadequate knowledge of the classics. Albucasis clearly believed that anatomic studies were the key to learning and certainly key in performing any surgical interventions. Although his thoughts on anatomic studies were excellent, Albucasis unfortunately popularized the frequent use of emetics as prophylaxis against disease, a form of medical treatment that survived in the form of “purging” and a medical practice that continued until well into the 19th century. So influential were Albucasis’s surgical writings that they remained in use in the schools of Salerno and Montpellier for approximately 500 years and had an enormous influence on medicine in the Middle Ages (Fig. 1-11).

The final section of the Compendium contains a lengthy summary of contemporary surgical practice.38-40 Also included in this part of Albucasis’s work is a unique collection of illustrations of surgical instruments. These illustrations became a long-lasting influence, inasmuch as his style of instrument was used extensively in the schools of Salerno and Montpellier and later became an important influence in the medieval period. Many of the instruments illustrated were probably designed by Albucasis. In the text, he clearly described their design, along with technical aspects of their use. Following up on the earlier writings of the Greeks, he provided a novel design for a “nonsinking” trephine. The design for this instrument and others became classic and formed the template for many later such instruments. An early and apparently unique technical innovation involved placing a collar on the trephine in a circular manner, a further and rather ingenious design to prevent the trephine from plunging into the brain. Some of the instruments were clearly copied from those described earlier by Paulus Aegineta, but their practical use was further enhanced by their inclusion in the Compendium.
Albucasis’s treatise on surgery is an extraordinary work in so many ways. The text is rational, comprehensive, well illustrated, and designed with the intent to educate the surgeon on details of each treatment, neglecting not even the types of wound dressings to be used. Albucasis’s techniques of brain surgery, however, were extremely crude. In fact, modern readers can only wonder how patients would allow themselves to undergo some of his surgical practices. For chronic headache, he applied a hot cautery to the occiput, burning through the skin but not the bone. Another headache treatment he described required hooking the temporal artery, twisting it, placing ligatures, and then, in essence, ripping it out.

For neurosurgeons, Albucasis identified and described various types of spinal injury. Albucasis recognized the seriousness of spinal injury, particularly dislocation of the vertebrae. In cases of total subluxation, he appreciated that the prognosis was essentially terminal because affected patients demonstrated involuntary activity (passing urine and stool), along with flaccid limbs. He was quite innovative in dealing with the lesser spinal injuries. In his surgical writings, Albucasis described and illustrated some of the methods and splints he used for reduction of such injuries. To modern readers, some of these techniques might seem to be dangerous in design, especially stabilizations that required an aggressive combination of spars and winches, as well as a “stretching” of the spinal column. Following earlier Greek and Byzantine views, Albucasis believed that bone fragments in the spinal canal should be removed. In reviewing skull fractures, Albucasis has an elegant discussion of the pediatric “ping-pong” fracture of the skull.

This is a fracture due to a fall or a blow from a stone and the like, making a dent in the surface of the bone and a hollow at the site as occurs in a bronze bowl when a blow falls on it and a portion of it is pushed in. This mostly occurs in heads whose bones are soft, as those of children.

The treatment of hydrocephalus was a vexing problem for surgeons and physicians because its outcome was almost always fatal. Albucasis recommended drainage of cerebrospinal fluid in hydrocephalus via a series of drains and wicks. He designed a lenticular shaped surgical tool to make the puncture, which was performed over the anterior fontanelle. Having detailed the technique well, he then noted the outcome is almost always fatal. Of interest is that the surgery was not the issue; rather, he attributed the poor outcomes to “paralysis” of the brain from relaxation. Albucasis cleverly pointed out that the physician must pick the technique well, he then noted the outcome is almost always fatal. Of interest is that the surgery was not the issue; rather, he attributed the poor outcomes to “paralysis” of the brain from relaxation. Albucasis cleverly pointed out that the physician must pick the site for drainage carefully and must never cut over an artery because the potential hemorrhage can rapidly lead to death. Some 20th century authors have advocated the treatment of hydrocephalus by binding the head with tight wraps. Albucasis was advocating this form of treatment more than 1000 years ago. For a child with hydrocephalus, he would bind the head with a wrap and then put the child on a “dry diet” with limited fluid intake to help dehydrate the child. In retrospect, this was a rather progressive and reasonable treatment plan for this disorder.

MIDDLE AGES: THE AGE OF MEDIEVAL MEDICAL SCHOLASTICISM

In the early Middle Ages, the influence of the Islamic/Arabic schools on medicine was beginning to lessen, along with a geographic switch in which intellectual centers for medicine were forming in Europe. With the advent of medieval scholasticism, a new school of thought developed in which philosophical and metaphysical explanations and dialectic interpretations became prominent in medical schools. One of the preeminent schools proposing this view was the School of Salerno in what is now Italy. In much of Europe, the barbarians were still in control, but despite that, physicians were being trained, and libraries were being built and expanded. Throughout Europe, new medical schools were being established at a steady rate.

At the School of Salerno, an early leader in developing medical scholasticism was Constantinus Africanus (1020-1087), magister orientis et occidentis. Constantine provided an important bridge in medicine by introducing the scholarship of Islamic/Arabic medicine at Salerno and eventually to all of Europe. Constantine received his medical education in Baghdad, learning the prevalent views of Islamic medicine. He moved to a monastery at Monte Cassino, where, in the tradition of this period, he translated Arabic manuscripts into Latin. Modern scholars believe that the translations were somewhat inaccurate and, as a result, introduced errors in the subsequent medical literature. In reviewing some studies, modern historians considered Constantine to be mostly a plagiarist and an unreliable translator. However, his translation of texts from Arabic to Latin were the earliest transfer of Arabic/Islamic medical literature into Europe, which was valuable. Nonetheless, because the original Greek texts had been translated into Arabic, and Constantinus translated the Arabic works into Latin, the legacy of Galen and other early writers remained firmly entrenched as dogma. Rather than providing or developing new ideas, the classical texts in medicine merely propelled medical dogma. How much medical and surgical knowledge was lost or distorted by inaccuracies in these successive translations is unimaginable.

Constantine did make a key contribution to medieval medicine when he reintroduced anatomic dissection with an annual dissection of a pig. Of interest is that as the dissection progressed, the findings were compared with those recorded in the Greek classics. If the dissector’s findings did not match those of the ancient texts, they were simply ignored! Constantine was clearly a learned scholar, but his style of teaching became typical of the Medical Ages. Extensive compilations and translations were undertaken, but original thought or advance in knowledge was notably lacking. In the Middle Ages, the School of Salerno did lead the way and was subsequently followed by the great medical schools at Naples, Bologna, Paris, and Montpellier, the early pillars of medieval medicine (Figs. 1-12 and 1-13).

An unusual and remarkable book was produced during this period: Regimen Sanitatis Salernitum [Salernitan Rule of Health], a work that first appeared in the 12th century and was later republished in approximately 140 different editions extending well into the 19th century. This book summarizes the Salernitan school directions for medical maintenance and care of patients. In Europe, a strong educational system was being developed, but the treatment of health care remained cloaked in the literature of classical Greeks and Islamic writing; for the most part, surgical

Figure 1-12. An illustration of Constantine the African lecturing at the School of Salerno. (Courtesy James Tait Goodrich, MD, PhD.)
education and surgical practice continued to be an avocation limited to uneducated barber-surgeons and apprentices. Nonetheless, there were a few exceptionally talented surgeons who developed some original surgical works and practices.

Roger of Salerno (Ruggiero Frugardi) (fl. 1170) is considered the first learned medieval European writer on surgery (Figs. 1-14 and 1-15). Roger was educated in the Salerno tradition and followed many of its teachings. His book on surgical practice, *Practica Chirurgiae*, offers several interesting surgical techniques of interest to neurosurgeons. An example was his technique for checking for a tear of the dura and leakage of cerebrospinal fluid in a patient with a skull fracture. To detect a leak, Roger would have the patient hold his or her breath and strain (i.e., the Valsalva maneuver) and then look for air bubbles around the fracture site, this being a clear sign of a leak. Roger was a pioneer in the techniques of managing peripheral nerve injury. For a severed nerve, he argued for reanastomosis of the nerve ends with close attention paid to their alignment. In dealing with the large bleeding veins of the neck, he urged direct ligation with a suture rather than cautery. For neurosurgeons, several chapters of his text are devoted to the treatment of skull fractures. Much of the described technique mirrors views of earlier classical writers, but the style is clearer and more succinct. This style is exemplified in this short description of management of various skull fractures:

> When a fracture occurs it is accompanied by various wounds and contusions. If the contusion of the flesh is small but that of the bone great, the flesh should be divided by a cruciate incision down to the bone and everywhere elevated from the bone. Then a piece of light, old cloth is inserted for a day, and if there are fragments of the bone present, they are to be thoroughly removed. If the bone is unbroken on one side, it is left in place, and if necessary elevated with a flat sound (spatumile) and the bone is perforated by chipping with the spatumile so that clotted blood may be

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_Figure 1-13. Title page from a collection of works of Constantine the African, 1536. (From Constantinus Africanus. Constantini Africani Post Hippocratem et Galenum. Basel: Henricus Petrus; 1536. Courtesy James Tait Goodrich, MD, PhD.)_  

_Figure 1-14. Illustrations of Roger of Salerno demonstrating brain and skull surgery. (From the Sloane manuscript 1977. Courtesy British Library Board.)_  

_Figure 1-15. Medieval manuscript on the writings of Roger of Salerno. The lower left image is a gilt-scribed image of Roger lecturing. (From the Sloane manuscript 1977. Courtesy British Library Board.)_
soaked up with a wad of wool and feathers. When it has consolidated, we apply lint and then, if it is necessary (but not until after the whole wound has become level with the skin), the patient may be bathed. After he leaves the bath, we apply a thin cooling plaster made of wormwood with rose water and egg.

A 12th-century manuscript owned by Harvey Cushing and attributed to Roger of Salerno contains an early description of a soporific for pain relief, for use in surgery. The soporific consisted of bark of mandragora (mandrake), hyoscyamus (henbane), and levisticum (lovage) seed, all of which were mixed together and ground and then applied wet to the forehead of the patient. In view of the ingredients, it was unlikely that this soporific was able to achieve any real pain relief. In Roger’s writings on surgical anatomy, many of the old errors persisted because of his recapitulating earlier anatomic treatises. Roger was particularly fond of citing the writings of Albucasis and Paulus Aegineta. He strongly favored therapeutic plasters and salvages but was not a strong advocate of the popular treatment of application of grease to injuries of the dura. Interestingly, Roger advocated the use of trephination in the surgical treatment of epilepsy, although he did not indicate why this technique would work. Chapters (capita) 1 to 13 are of particular interest to neurosurgeons because they detail contemporary surgical treatment of scalp wounds and fractures of the skull. One of Roger’s most significant errors in surgical practice was the concept that provoking pus suppuration in a wound encouraged healing. The concept of “laudable pus” in wound healing was introduced here and seriously hampered wound care until the time of Sir Joseph Lister and 19th-century antisepsis.

An unusually talented and inventive medieval surgeon from Bologna was Theodoric of Cervia (Borgognoni) (1205–1298). In comparison with Roger of Salerno, Theodoric was a pioneer in the use of aseptic technique; not the “clean” aseptic technique of today, but rather a method based on avoidance of “laudable pus.” Theodoric believed that he had found the ideal conditions for good wound healing, which included control of bleeding, removal of contaminated or necrotic material, avoidance of dead space, and careful application of a wound dressing bathed in wine, the last providing a degree of antisepsis. He also argued for primary closure of all wounds when possible and avoiding “laudable pus”.

For it is not necessary, as Roger and Roland have written, as many of their disciples teach, and as all modern surgeons profess, that pus should be generated in wounds. No error can be greater than this. Such a practice is indeed to hinder nature, to prolong the disease, and to prevent the conglutination and consolidation of the wound.

Theodoric’s surgical work was first written in 1267, and it is one of the best reviews of contemporary medieval surgery. He is also remembered as one of the earliest writers to include illustrations of his techniques in his book. Theodoric surgical technique called for meticulous (almost Halstedian) techniques, with gentle handling of surgical tissues being key. Theodoric believed that aspiring surgeons should train only under competent masters. In the field of head injury, Theodoric argued that parts of the brain could be removed through a wound with little effect on the patient. In the treatment of skull fractures, he strongly argued for elevating depressed fractures. Theodoric advocated avoiding any punctures of the dura because these could lead to abscess and convictions, thereby resulting in adverse outcomes. For pain relief during surgery, he developed his own “soporific sponge,” containing opium, mandragora, hemlock, and other less important ingredients, which he applied to the patient’s nostrils; once the patient fell asleep, Theodoric began surgery. Opium was probably the key ingredient in this recipe.

William of Saliceto (Guglielo da Saliceto) (1210–1277) was a uniquely skilled Italian surgeon and a professor at the University of Bologna. William’s book on surgery, Chirurgia (or Cyrrurgia), completed in 1275, contained some highly original concepts that were not totally based on previous classical writings but in which the influence of Galen and Avicenna is clear. This book was written by William for his son Bernardino. The text is mostly original and based on his own observations. Rarely did William quote other writers. Book IV contains the earliest known treatise on surgical and regional anatomy. His most significant contribution during this era was his decision to discard the surgical technique of burning with cautery and use instead the surgical knife:

De anathomia in communi et de formis membrorum et figures que sunt considerande in incision et cauterizatione.

[The anatomy of the members and the figures concerning the forms of which are to be considered in general and in the incision and cauterization.]

William’s writings contain some interesting and unique techniques for a primary peripheral nerve suture repair. In this pre-Harveian era, he was able to distinguish arterial bleeding from venous bleeding by the “spurtling” of blood. William’s views on the brain were also unique by contemporary standards, inasmuch as he put forth some interesting neurological concepts that the cerebrum governs voluntary motion and the cerebellum involuntary function.

Leonardo of Bertapaglia (ca. 1380–1460) was a prominent 15th-century Italian surgeon and writer. Leonardo established an extensive and lucrative practice in the area of Padua and in neighboring Venice. At a time when anatomic dissection was rarely practiced in Europe, Leonardo became one of the earliest proponents of the study of anatomy. In 1429 he offered a course of surgery that included the dissection of an executed criminal. Leonardo devoted one third of his book to surgery of the nervous system and head injuries. He considered the brain the most precious of organs, regarding it as the source of voluntary and involuntary functions. In his treatment of skull fractures, he always avoided materials that might generate pus. Leonardo argued for never placing a compressive dressing that might drive bone into the brain; if a piece of bone pierced the brain, the surgeon was to remove it.

Leonardo put together a set of rules to guide the practice of a 15th-century surgeon that are still applicable five centuries later:

To be the perfect surgeon, you must always bear in mind these eight notations, and remembering them you will be preferred to others.

The first task…to become a good surgeon should be to use his eyes….

Second, you must accompany and observe the qualified physician, seeing him work before you yourself practice….

Third, you must command the most gentle touch in operating and treating lest you cause pain to the patient….

Fourth, you must insure that your instruments be sharp and untrusted whenever you cut anywhere….

Fifth, you must be courageous in operating and cutting but timid to cut in the vicinity of nerves, sinews and arteries, and, so as not to commit error, you should study anatomy, which is the mother of this art…perform your surgery cleverly and never operate on human flesh as if you were working on wood or leather….

Sixth, you must be kind and sympathetic to the poor, for piety and humility greatly augment your reputation and the sick will more freely commit themselves to your care.

Seventh, you must never refuse anything brought you as a fee, for the sick will respect you more.

Eighth, you must never argue about fees with the sick, or indeed demand anything unless it be previously agreed upon, for avarice is the most ignoble of vices and should you be so inflicted, you will never achieve the reputation of a good doctor.
Historical Overview of Neurosurgery

Lanfranchi (Lanfranc) of Milan (c. 1250-1306) was a pupil of William of Saliceto and was often referred to as the father of French surgery. Lanfranchi also advocated his teacher’s use of the knife in place of the burning cautery. Although born and educated in Italy, he had to leave Italy for France to avoid political strife. His Cyrurgia Parva details a number of interesting surgical techniques. Lanfranchi perfected the use of the suture for primary wound repairs. He was among the first to associate the direct effect of head injury on brain function. Hippocrates had been the first to articulate the concept of commotio cerebri, but Lanfranchi provided the first modern characterization of what is now known as a cerebral concussion. For surgeons, he developed a series of guidelines for trephination in skull fractures and “release of irritation” of dura. Because of the dangers of skull surgery, Lanfranchi argued for employing the trephine only when absolutely necessary; for other cases, he invoked the skills of the “Holy Ghost” to provide the cure. Among his innovative surgical techniques was the development of esophageal intubation during surgery, a technique not commonly practiced until the 19th century. As an educated surgeon and a “surgeon of the long robe” (i.e., academic), he attempted to elevate the art and science of surgery above the mediocre level of the menial barber-surgeon (“surgeons of the short robe”). Lanfranchi also argued against the separation of surgery and medicine, advocated since the time of Avicenna, believing that a good surgeon should also be a good physician (Fig. 1-16).

Another important person in the history of French medicine and surgery was Henri de Mondeville (c. 1260-1317). Educated in Paris and Montpellier, Henri later went on to become a professor at Montpellier. Henri was strongly motivated to elevate the profession of surgeon, and he clearly detested the barber-surgeons, stating, “Most of them were illiterates, debauchees, cheats, forgers, alchemists, courtiers, procurees, etc.”

In 1306 Henri undertook the task of developing a new treatise on surgery for the education of his students at Montpellier. Unfortunately, because of tuberculosis and general ill health, he never completed the manuscript; the edited portions were not published until 1892, when Professor Julius Pagel of Berlin completed the task. Henri adopted and followed a number of the views of Lanfranchi. He was a believer in clean wounds and avoiding “laudable pus.” Unfortunately, Henri would be the last surgeon in this era to argue for avoiding “laudable pus.” Subsequent surgeons returned to the older belief that the development of pus in a wound was a good sign of healing. Henri offered some originality in wound management by advocating for healing by primary intention: modus novus noster. In surgical treatment of wounds, he encouraged the removal of foreign bodies and the use of wine dressings in wound care, the wine acting as an antiseptic and providing better healing. Henri’s designs of a number of surgical instruments were clever. He is remembered for the design of a needle holder and also a forceps-type instrument for extraction of arrowheads. Henri was a bit more conservative than his predecessors in dealing with head injuries. He argued against elevating skull fractures if there was no injury to the overlying soft tissues, believing that nature would do a better job of healing the fracture by natural union. It was his opinion that unnecessary exploration and probing of the wound would only cause more injury than natural healing: in retrospect, such an insight into wound care was brilliant.

No history of surgery can be complete without a discussion of the contributions of Guy de Chauliac (1300-1368). He was clearly the most influential European surgeon of the 14th and 15th centuries. He was so highly respected that he became physician to three popes at Avignon (Clement VI, Innocent VI, and Urban V) and leading surgeon and educator at the school of Montpellier. Guy was educated in Toulouse, Paris, Montpellier, and Bologna. He was an early proponent of anatomic dissection of a human cadaver. He stated, “In these two ways we must teach anatomy on the bodies of men, apes, swine, and divers other animals, and not from pictures, as did Henri de Mondeville who had thirteen pictures for demonstration of anatomy.” His writings were popular and continued to exert an influence on surgery until well into the 17th century. His principal didactic surgical text, scribed in 1363, was titled the Collectorium Cyrurgie.

There are 34 known manuscripts of this work; the first printed edition appeared in 1478, and more than seventy editions have been published since (Fig. 1-17).

In promoting surgeons as individuals more skilled than “mechanics” (i.e., barber-surgeons), he stated four conditions that must be satisfied for a practitioner to be a good surgeon: (1) the surgeon should be learned; (2) he should be expert; (3) he must be ingenious; and (4) he should be able to adapt himself (from the introduction of Ars Chirurgica). Guy devised interesting techniques for the treatment of head injuries. For example, before the beginning of surgery, he recommended shaving the patient’s head so as to prevent hair from getting into the wound and interfering with primary healing. For depressed skull fractures, Guy preferred to put wine-soaked cloths into the injured site to assist healing. He categorized head injuries into seven types and discussed the management of each in detail. He believed that scalp wounds required only cleaning and débridement but that a compound depressed skull fracture must be treated by means of trephination and elevation. Skin closure was done by primary repair, for which he claimed good results. To help control excessive bleeding and provide hemostasis, he used egg albumin. For reasons that are not at all clear, Guy set back good surgical healing by readopting the views of “laudable pus” as being good for wound healing. “Laudable pus” remained part of surgical healing until the middle of the 19th century. Guy’s interest in wound healing and healing by primary intention has not been lost; however, his emphasis on the use of antiseptics was a significant contribution to modern surgery.
practice and was not to be corrected until the works of Sir Joseph Lister nearly 500 years later.

As England was moving away from the period of barbarian invasions and into the Middle Ages, university education in England began to become comparable with the European model. The leading surgeon of this period in England was John Arderne (Arden) (1307-1380), who trained as a military surgeon and had much war experience. In 1370 he came to London and joined the Guild of Military Surgeons. He characterized himself as chirurgus inter medico (a surgeon among physicians). His manuscripts on surgery were written circa 1412. This manuscript, De Arte Phisicali et de Cirurgia, translated into English by D’Arcy Power in 1922, was a valuable addition to the English literature on early surgery. John Arderne was evidently a very skilled surgeon with a number of practical insights into what could or could not be done surgically. He believed firmly in clean hands and well-shaped nails for surgery, although some writers have thought that this was more for social reasons than surgery. In addition, he would bathe his open wounds with an irrigation that contained turpentine, a useful surgical antiseptic for keeping wounds clean. Of most importance, John Arderne was a firm believer in education and learning. In addition, he wrote that the surgeon must “always be sober during any surgery as drunkenness destroys all virtue and brings it to naught.”

The late Byzantine/Islamic and medieval periods were an era of great misguided intellectual activity and of unoriginality of thought. Clearly the educators had more faith in the teachings of antiquity. From the fall of the Roman Empire to the beginning of the 16th century, anatomy and the practice of surgery, with only rare exceptions, remained stagnant, guided by a staunch Galenic and Hippocratic orthodoxy. The translation of medical manuscripts from Latin, Greek, and Hebrew into Arabic and back into Latin resulted in many errors of translation and interpretation. The combination of a lack of anatomic knowledge and poor surgical outcomes naturally led physicians to recommend against operating on the brain, except in simple cases. A review of the work done by the surgical physicians just described reveals that despite a period of intellectual paralysis, a number of prominent physicians did make some advances. It is clear that monastic recluses in often-inaccessible mountain retreats carefully guarded medical knowledge, but despite this state of affairs, some surgeons clearly succeeded in mastering their art in the midst of intellectual darkness.

The history of medicine consists of a successive series of intellectual movements proceeding from different centers and each engulfing its predecessor.

**ORIGINS OF NEUROSURGICAL PRACTICE IN THE RENAISSANCE**

With the Renaissance came interesting innovations in surgical concepts and techniques. Beginning in the mid-15th century, physicians and surgeons introduced basic investigative techniques to learn human anatomy and physiology. Of enormous significance was the introduction of routine anatomic dissection in medical schools. Moving away from subservience to the medievalists, great physicians such as Leonardo da Vinci, Jacopo Berengario da Carpi, Nicholas Massa, and Andreas Vesalius explored the human body without being encumbered by the erroneous writings of earlier authors. Codified anatomic errors, many enshrined since the Greco-Roman era, were being corrected. A better understanding of human anatomy led to a change of epistemologic presuppositions, which led to a great surge of interest in surgery. Putting the teachings of antiquity aside, surgeons began, with great vigor and enthusiasm, to investigate medical mysteries. As a result of this shift from the somber and somnolent intellectual darkness, the early foundations of modern neurosurgery were laid.

Any discussion of Renaissance surgery and anatomy has to begin with Leonardo da Vinci (1452-1519), the quintessential Renaissance man. Multitalented, recognized as an artist, an anatomist, and a scientist, da Vinci used the dissection table to better understand surface anatomy and its relationship to art and sculpture. From his studies, da Vinci is now recognized as the founder of iconographic and physiologic anatomy. He provided the earliest, albeit crude, diagrams of the cranial nerves, the optic chiasm, and the brachial and lumbar plexi. He developed a wax casting technique that allowed him to work out and understand the anatomy of the ventricular system. To do this, he took a fresh brain and poured a liquid wax into the ventricles and placed a hollow tube to allow egress of the air. His experimental studies included sectioning a digital nerve in a living person and noting that the affected finger no longer had sensation, even when placed in a fire. Da Vinci was not a surgeon, but he gave an important impetus to the study of anatomy and the defining of correct anatomic relationships—vital concepts for any surgeon. Unfortunately, he died before he could finish his great opus on anatomy, which was to be published in approximately 120 volumes. His anatomic manuscripts did circulate among the artist community in Italy throughout the 16th century, only to be lost; then they were rediscovered in the 18th century by William Hunter (1718-1783). These anatomic works had a profound influence on artists and physicians and subsequently on the development of modern anatomic studies. Da Vinci, as a founder of modern anatomy, provided a creative spark to reexplore the human body by hands-on dissection (Figs. 1-18 to 1-20).
CHAPTER 1  Historical Overview of Neurosurgery

The earliest printed surgical work to contain illustrations was *Dis Ist das Buch der Cirurgia*, authored by Hieronymus Brunschwig (ca. 1450-1512) and published in Strasbourg in 1497. Although the images have nothing to do with specific surgical procedures, the book is the first to discuss the management of gunshot wounds; gunpowder had only just recently been introduced in weapons of war. This work was considered to be valuable enough to be plagiarized and published in a pirated edition the same year and appeared in many other editions throughout the 16th century. In the 1513 edition, the first illustration of a patient with a head injury undergoing treatment was added to the work (Fig. 1-21).

One of the early Renaissance surgeons who incorporated some of the recently revealed anatomic concepts was Hans von Gersdorff (1455-1529). In his surgical book *Feldtbüch der Wundartzney*, published in 1517, are some of the earliest illustrations on surgical technique. Gersdorff was a military surgeon and,
with more than 40 years of war experience, became quite adept at handling battlefield injuries. This handbook for surgeons was divided into four parts: anatomy, surgery, leprosy, and a glossary of anatomic terms, diseases, and medications. The section on anatomy was based on his own extensive experience, and he used the earlier writings of the Islamic physicians and the works of Guy de Chauliac. The surgical portion deals with military surgery, mostly on how to extract foreign objects, tourniquet techniques to control bleeding, and amputation techniques. Several woodcuts dealing with surgical technique and surgical instrumentation are of interest to modern neurosurgeons; one woodcut clearly illustrated a third nerve palsy on the side of the depressed skull fracture and a facial paralysis on the opposite side. Included in this work is also the first plate showing a dissection of the human brain. This surgical work became very popular and was published in several editions; this was because of both its practical presentation of surgery and the illustrations in the text (Fig. 1-22).

One of the greatest physicians in the history of surgery remains Ambroise Paré (1510-1590), a poorly educated, humble Huguenot, an individual whom many historians have considered the father of modern surgery. After extensive military surgical experience, Paré was able to organize and publish a great deal of practical knowledge, along with innovative instrument designs. At this time, most physicians and surgeons published their writings in Latin; Paré preferred to publish in French instead. Paré’s books therefore were more widely disseminated and appreciated. As his reputation grew, Paré became a valued surgeon to the European royal courts. One of Paré’s most famous cases was a head injury sustained by Henri II of France. Paré (and also Andreas Vesalius) attended the king and was also present at the autopsy. Henri II had suffered penetrating right orbital injury and a subdural hematoma after a joust during the celebration of the marriage of his daughter, Elizabeth of France, to Philip, King of Spain. When Paré described the clinical findings in Henri II, he noted that the patient complained of a headache and blurred vision. Henri II went on to develop vomiting, lethargy, and ominous signs of decreased respiration, and he died 11 days after the injury. Paré postulated that the injury was caused by a tear in one of the bridging cortical veins, and he was clearly describing signs of increased intracranial pressure. Paré’s remarkable clinical observations and clinical history were confirmed at autopsy. Thus, despite humble beginnings, Paré became one of the most celebrated physicians in this formative period of surgery (Figs. 1-23 and 1-24).

Paré commented on the “surgeon’s duties”:

Five things are proper to the duty of a Chirurgeon: To take away that which is superfluous; to restore to those places such things as are displaced; to separate those things which are joined together; to join those which are separated and to supply the defects of nature. Thou shalt far more easily and happily attain to the knowledge of these things by long use and much exercise, than by much reading of Books, or daily hearing of Teachers. For speech, how perspicuous and elegant soever it be, cannot so vividly express anything, as that which is subjected to the faithful eyes and hands.

Among Paré’s surgical works, his writings on the brain remain the most remarkable. Book X is devoted to the diagnosis and management of skull fractures. Although it was not an original idea, Paré popularized the interesting technique of elevating a depressed skull fracture through the use of the Valsalva maneuver:

...for a breath driven forth of the chest and prohibited passage forth, swells and lifts the substance of the brain and meninges where upon the frothing humidity and sanies sweat forth.
Berengario dreamed that he was visited by a man wearing a cap adorned with a rooster feather and golden-winged sandals (i.e., Hermes Trismegistus, or the Third Mercury), who encouraged Berengario to write a treatise on skull fractures and head injuries. The result was a marvelous tractatus, the first printed work devoted solely to injuries of the head. In the text, original surgical techniques are discussed, along with the earliest illustrations of cranial instruments designed for surgical treatment of head injury. As an anatomist, Berengario, like Leonardo da Vinci, provided one of the earliest and most complete discussions of the ventricular system. Berengario presented some of the earliest descriptions of the pineal gland, choroid plexus, and lateral ventricles.70 His anatomic illustrations are among the first published from actual anatomic dissections. He was a firm believer in anatomic dissection because that was the only way to learn the anatomy; he believed that the written word alone was useless, and he observed that the earlier writings were full of anatomic errors. His anatomic writings were among the first to challenge the medieval dogmatic writings of Galen and others (Figs. 1-25 to 1-27).

A less known writer and anatomist of the Renaissance was a Marburg professor by the name of Johannes Dryander (Johann Eichmann) (1500-1560). In 1536, Dryander published an illustrated work (expanded in 1537) on the brain and skull.71,72 Within this most remarkable work are 16 plates of the brain, showing successive layered dissections of the scalp, dural coverings, and the brain itself. The drawings of the anatomy of the cerebellum and the posterior fossa are particularly striking. There are inaccuracies in the text because of the prevailing influence of Galen and medieval scholasticism; nonetheless, this book can be considered the first textbook of neuroanatomy. Despite Dryander’s allegiance to Galen’s teaching, he advocated public anatomic

Berengario dreamed that he was visited by a man wearing a cap adorned with a rooster feather and golden-winged sandals (i.e., Hermes Trismegistus, or the Third Mercury), who encouraged Berengario to write a treatise on skull fractures and head injuries. The result was a marvelous tractatus, the first printed work devoted solely to injuries of the head. In the text, original surgical techniques are discussed, along with the earliest illustrations of cranial instruments designed for surgical treatment of head injury. As an anatomist, Berengario, like Leonardo da Vinci, provided one of the earliest and most complete discussions of the ventricular system. Berengario presented some of the earliest descriptions of the pineal gland, choroid plexus, and lateral ventricles.70 His anatomic illustrations are among the first published from actual anatomic dissections. He was a firm believer in anatomic dissection because that was the only way to learn the anatomy; he believed that the written word alone was useless, and he observed that the earlier writings were full of anatomic errors. His anatomic writings were among the first to challenge the medieval dogmatic writings of Galen and others (Figs. 1-25 to 1-27).

A less known writer and anatomist of the Renaissance was a Marburg professor by the name of Johannes Dryander (Johann Eichmann) (1500-1560). In 1536, Dryander published an illustrated work (expanded in 1537) on the brain and skull.71,72 Within this most remarkable work are 16 plates of the brain, showing successive layered dissections of the scalp, dural coverings, and the brain itself. The drawings of the anatomy of the cerebellum and the posterior fossa are particularly striking. There are inaccuracies in the text because of the prevailing influence of Galen and medieval scholasticism; nonetheless, this book can be considered the first textbook of neuroanatomy. Despite Dryander’s allegiance to Galen’s teaching, he advocated public anatomic
dissections, the results of which included these remarkable neuroanatomic drawings (Figs. 1-28 and 1-29).

Military surgery has always been a great educator of surgeons, and one of those particularly influenced by his military service was Volcher Coiter (1534–1576). Coiter was an army surgeon and city physician in Nuremberg who had the good fortune to study under several contemporary experts, including Gabriele Fallopis, Bartolomeo Eustachius, and Ulisse Aldrovandi. As a result of their teachings and education, Coiter was able to undertake unique and original anatomic and physiologic investigations. Among his anatomic descriptions were the first anatomically correct details of the anterior and posterior spinal roots. He was the first to distinguish gray from white matter in the spinal cord. Coiter had a particularly strong interest in the spine, which led him to conduct a number of anatomic and pathologic studies of the spinal cord, including an early model of decerebrate posturing. Coiter also provided a number of details on how to trephine skulls of birds, lambs, goats, and dogs. He was the first to associate the pulsation of the brain with the arterial pulse. As an early neurosurgeon and investigator, he reported on opening the brain and removing parts of it with no ill effects noted: an early, surprising precursor attempt at cerebral localization.

One of the most skilled of Renaissance surgeons was a Venetian, Giovanni Andrea della Croce (c. 1509–1580). Della Croce was a follower of Paré and adopted many of his techniques and beliefs. A combination of surgical skill and a Renaissance flair for design led della Croce to produce a remarkable book on surgery in 1573. Within this monograph are some of the most beautifully engraved scenes of neurosurgical operations. As was typical for the period, surgical operations were performed in family homes, typically in the bedroom (with the occasional dog lying at the foot of the bed). Della Croce verbally, and in drawings, described the techniques for performing trephinations. Several illustrations show the various types of arrows, spears, and bullets used in warfare, and the techniques for their removal are detailed. An additional series of plates shows his instrument designs for performing neurosurgical procedures. One illustration is of a bloody trephination being performed with minimal anesthesia—a concept considered horrific by modern readers—in a beautifully appointed nobleman’s bedroom (Figs. 1-30 and 1-31).

Della Croce illustrated a number of trephination instruments in this monograph, some of which were an improvement on their predecessors. Della Croce’s trephination drill was rotated by means of an attached bow, in the manner of a carpenter’s drill. Various trephine bits are proposed and illustrated, many surprisingly modern, with conical designs to avoid plunging. The illustrations of surgical instruments include Penfield-style elevators for lifting depressed skull bone.

An expert in surgery and anatomy whose work typifies the great strides of learning in the Renaissance was Andreas Vesalius (1514–1564). Vesalius was educated at Louvain, Montpellier, and Paris, all staunch schools of Galenic orthodox teaching. Rejecting the views of his Galen-enthralled professors, Vesalius provided an innovative and dramatic approach to anatomic dissection (Figs. 1-32 and 1-33). Following up on the theme of the earlier 16th century anatomists such as Leonardo da Vinci and Jacopo Berengario da Carpi, Vesalius argued that anatomic dissections had to be performed by the teacher, not by an ignorant prosector being guided by a professor who sat at the lectern reading from a Galenic monograph on anatomy.
CHAPTER 1 Historical Overview of Neurosurgery

Figure 1-27. Title page with an allegorical anatomic dissection scene from Jacopo Berengario da Carpi’s 1522 work on anatomy. (From Berengario da Carpi J. Isagoge Breves: Perlucide ac Uberrimae in Anatomia Humani Corporis: A Co[m]uni Medicorum Academia Usitatum…. Bononiae, Italy: B. Hectoris; 1522. Courtesy James Tait Goodrich, MD, PhD.)

Figure 1-28. Title page from Johannes Dryander’s work on the anatomy of the human brain. This work included the earliest realistic illustrations of brain anatomy. (From Dryander J. Anatomiae. Marburg, Germany: Eucharius Cervicornus; 1537. Courtesy James Tait Goodrich, MD, PhD.)

Figure 1-29. A. Johannes Dryander’s illustrations of scalp and skull dissection, revealing the dura and brain in layers. B. “Cell doctrine” theory within the ventricular system, as illustrated by Dryander. (From Dryander J. Anatomiae, Marburg, Germany: Eucharius Cervicornus; 1537. Courtesy James Tait Goodrich, MD, PhD.)
Vesalius was appointed professor of anatomy at Padua at the young age of 23. At the age of 28, in 1543, Vesalius produced his great work, *De Humani Corporis Fabrica*. Book VII is an extensive discussion on the anatomy of the brain. Included in the chapter are detailed anatomic discussions with excellent illustrations. Following up on his anatomic caveats, Vesalius noted the “heads of beheaded men are the most suitable [for study] since they can be obtained immediately after execution with the friendly help of judges and prefects.”

Vesalius was also trained as a surgeon. The *Fabrica* contains a section of text on the brain and the dural coverings in which Vesalius discussed mechanisms of brain injury and how the various membranes and bone have been designed to protect the brain. In his second edition of *Fabrica* (1555), Vesalius provided an early and interesting case of a child with hydrocephalus and remarked on the condition as originating from cerebrospinal fluid; however, Vesalius was unable to offer any surgical treatment: “…in ipsius cerebri cavitate, adeoque in dextro sinistroque illius ventriculis: quorum cavitas amplitudoque ita increverat, ipsumque cerebrum ita extensus fuerat, ut novem fere aquae libras…continuerint” [“In the same brain cavity, the right and left ventricles’ cavity space thus increased, and the brain was so spread out; nearly nine pounds of water…was contained”]. Of interest is that several of the initial letters in the text are illustrated with little cherubs performing trephinations!

A contemporary of Vesalius and another leader in Renaissance anatomic studies was a Parisian anatomist, Charles Estienne (1504-1564). His book on anatomy, *De Dissectione Partium Corporis Humani Libri Tres*, was actually completed in 1539, thereby predating Vesalius’s work by 4 years, but legal problems delayed its publication until 1546. This book is most notable for a wealth of beautiful anatomic plates dealing with neuroanatomy. It contains representations of a series of anatomic figures with the subjects posed against sumptuous and imaginative Renaissance backgrounds. In the text, the anatomic details are not as original as Vesalius’s anatomic treatise. In addition, many of the errors introduced by Galen and his followers are repeated in Estienne’s text descriptions. However, the plates on the nervous system are quite graphic and among the most illustrative of this period. An important work, albeit with errors, it does detail the anatomy of the skull and brain more accurately than did previous works (Figs. 1-34 and 1-35).

In view of the contributions of the aforementioned physicians and their works, advances made in the Renaissance were clearly remarkable. Back in vogue was originality in anatomic research, replacing the ex cathedra writings of Galen and the classicists. No surgeon could explore the human body without an accurate understanding of the underlying anatomy. In addition, during the Renaissance, important events included the introduction of the printed book and the production of accurate anatomic illustrations.

The Hippocratic emphasis on the skull fracture continued to dominate the management of head injuries, as it had for the preceding 2000 years. With developments in anatomic knowledge now well under way, the next era was an understanding of
The 17th century, the so-called insurgent century, carried these themes even further with significant achievements in science and medicine. Some historical “giants” produced their scientific contributions during this century: Isaac Newton (1642-1727), Francis Bacon (1561-1625), William Harvey (1578-1657), and Robert Boyle (1627-1691) contributed their ideas and innovation in the introduction of physics, experimental design, discovery of the circulation of blood, and physiologic chemistry. Another critical advance was the formation of scientific societies, with the first
open public presentations of scientific ideas. Among the most important societies were the Royal Society of London, the Académie Des Sciences in Paris, and the Gesellschaft Naturforscher in Germany. Thus scientific education and exchange of information were advanced. For the first time, scientific ideas and information could be distributed publicly, and their merits discussed, in open dialogue.

A distinctive scholar of this period in the early understanding of the brain was Thomas Willis (1621-1675), an early describer of the eponymous circle of Willis, familiar to every physician. Willis was educated at Oxford and became a fashionable London physician (Fig. 1-36). Willis published a number of important monographs, but the one that stands out is his *Cerebri Anatomie*, published in London in 1664. With methodic attention to detail, this book became the most accurate anatomic study of the brain to date. Willis was assisted in this work by Richard Lower (1631-1691) in demonstrating that when parts of the “circle” were tied off, the anastomotic network still provided blood to the brain. The superb and anatomically accurate engravings of the brain (Fig. 1-37) were produced by Sir Christopher Wren (1632-1723).

Willis introduced the concept of *neurology*, or the doctrine of neurons. Willis used the term in a purely anatomic sense, inasmuch as the concept of “neurological” disease had not yet been
Neurology as a noun did not enter general use until Samuel Johnson (1709-1784) defined it in his dictionary of 1765.81 At this point, neurology came to be understood as the entire field encompassing anatomy, function, and physiology. It is also worth noting that the circle of Willis was not described uniquely by Willis; other anatomic descriptions of this circle were provided in several contemporary anatomic publications (the reader is referred to the writings of Vesling,82 Casserius,83 Fallopia,84 and Ridley85).

A prominent anatomist at this time and one often overlooked by contemporary writers was Humphry Ridley (1653-1708). Ridley was educated at Merton College, Oxford, and at the University of Leyden, where he received his doctorate in medicine in 1679. Ridley produced an important anatomic work on the brain, The Anatomy of the Brain, written in English, which became widely circulated and influential (Figs. 1-38 and 1-39).

The Anatomy of the Brain was published in London in 1695.85 At the time his work on the brain appeared, many of the classic Greek views of the brain were in vogue. Seventeenth-century anatomy and medicine moved away from the earlier “cell doctrine” theory (in which brain function was considered to reside within the ventricles); anatomists had begun to recognize the brain as a distinct anatomic entity. In contrast to the “cell doctrine,” cerebral function came to be viewed as a property of the brain.86,87

Ridley recorded a number of original observations. Ridley’s description of the circle of Willis was even more accurate in details than Willis’s and included a more complete anatomic description of both the posterior cerebral artery and the superior cerebellar artery, defined as separate entities. Anatomists had begun to recognize the brain as a distinct anatomic entity. In contrast to the “cell doctrine,” cerebral function came to be viewed as a property of the brain.86,87

Ridley recorded a number of original observations. Ridley's description of the circle of Willis was even more accurate in details than Willis's and included a more complete anatomic description of both the posterior cerebral artery and the superior cerebellar artery, defined as separate entities. Ridley provided a better demonstration of the principle of anastomotic flow and better elucidated the anastomotic principle of this network with his anatomic studies. To conduct his studies, Ridley had access to recently executed criminals. The method of execution was typically hanging, which caused vascular engorgement of the brain and thus facilitated identification of the vascular anatomy. Ridley's understanding of the deep nuclei of the cerebellum, particularly the anatomy of the posterior fossa, was superior to Willis's. Ridley also provided one of the earliest descriptions of the arachnoid membrane. Of note, Ridley still believed in the rete mirabile, a tenacious holdover from Galenic times. To Ridley this was a legitimate anatomic structure, and he provided a strong argument for its existence in this monograph. In addition, Ridley provided the first accurate description of the fornix and its pathways in this monograph. This volume and the work by Willis presented the first scientific anatomic studies of the brain and thereby provided an essential anatomic foundation for future neurosurgeons.

A surgical expert often overlooked in neurosurgical history is Wilhelm Fabricius von Hilden (1560-1634). Although Fabricius (also known as Faby) had received a classical education in his youth, family misfortune did not allow him to go on to a formal medical education. He went on to study in the “lesser field” of surgery, being educated in the apprentice system then prevalent. Fortunately, the teachers who trained him were among the finest wound surgeons of the day. Lacking a formal university education and excelling with a surgical apprentice education, he went on to develop a distinguished career in surgery.

Fabricius produced one of the most important surgical works of the 17th century: Observationum et Curationum, a monograph that included more than 600 surgical cases, along with a number of important and original observations on the brain.88 Fabricius’s observations on the brain and surgery included descriptions of a number of congenital malformations, skull fractures, and techniques for bullet extraction, along with original designs for field surgical instruments. He described operations for intracranial hemorrhage (with cure of insanity), vertebral displacement, congenital hydrocephalus, and an occipital tumor in the newborn (probably an encephalocele). Fabricius carried out trephinations for treatment of a brain abscess and cure of a longstanding...
aphasia. He even removed a splinter of metal from an eye by using a magnet, a cure that only enhanced his reputation (Figs. 1-40 and 1-41).

Some early and skillfully designed neurosurgical instruments are illustrated in a work by **Johann Scultetus (Schultes)** (1595-1645) of Ulm, titled *Armamentarum Chirurgicarum XLIII*. Scultetus provided unique and graphic details of neurosurgical instruments, clearly the finest to appear since those published by Berengario in 1518 and della Croce in 1573. The illustrations graphically reveal surgical techniques for treating fractures and dislocations, along with a variety of bandaging techniques for dealing with wounds. This surgical work was so popular that it was translated into many languages, including English, and it exerted a considerable influence on surgery throughout Europe for more than two centuries. The surgical plates and descriptions of various operations contain exacting details, including concepts from antiquity to the present. Of interest is that many of the instruments illustrated by Scultetus remain in use today. Scultetus’s details of surgical operations for injury of the skull and brain are remarkable plebscise (Figs. 1-42 and 1-43).

Neurosurgical practice continued to evolve in the 17th century. A surgeon who offered some interesting technical advice on developing neurosurgical operating skills was **John Woodall** (c. 1536-1643). Woodall was a military surgeon by training and surgeon-general to the East India Company. For surgeons of the East India Company, he compiled a surgical monograph titled *The Surgeon’s Mate* (1617). In his collected works, published in 1639, Woodall provided a list of surgical instruments and sound...
advice for a surgical practice.\textsuperscript{91} Woodall fabricated a trephine with a then-unique design of a crown that included a center pin; this innovation prevented the crown from slipping on a bloody skull. A brace was added to this trephine, which could be placed against the surgeon’s chest for additional support and driving force. This innovative design allowed the surgeon to drive the trephine with one hand while the other held the head, all of which could be accomplished on a rolling ship’s deck. Woodall, recognizing the ignorance of his contemporary German surgeons, believed that a surgeon should practice trephining on sheep or calf skulls first before performing one on a human head (Figs. 1-44 and 1-45):

“The Germane Surgeons use no Trapan, that ever I could see my eight years living among them, though they both speak and write of it. But for as much as it is apparent, the work of a Trapan is very good, I therefore would advise a young Artist to make some experience first upon a calves head, or a sheepe’s head, till he can well and easily take out a piece of the bone; so shall he the more safely do it to a man without error when occasion is.”

(J. Woodall, The Surgeon’s Mate,\textsuperscript{91} p 4)

An Englishman and Plymouth naval surgeon, James Yonge (1646-1721), was among the first to argue emphatically that “wounds of the brain are curable”; Galen had earlier announced, “I have seen the wounded brain heal.”\textsuperscript{92} Yonge’s first surgical text was a small monograph titled Wounds of the Brain Proved Curable.\textsuperscript{92} Yonge provided a surgical account of a brain operation on a child of 4 with extensive compound fractures of the skull from which brain tissue issued forth. The surgery was successful, with the child surviving, and this inspired Yonge to publish the account. Yonge also reported on more than 60 cases in which brain wounds were cured that he was able to locate in the older literature,
The 17th century clearly provided a sound scientific and anatomic basis for neurosurgery and neurosciences. The 18th century continued this trend and was a period of intense activity in the medical and scientific world. Chemistry as a true science was being propelled forward in the works of Joseph Priestley (1733-1804), Antoine Lavoisier (1743-1794), Alessandro Volta (1745-1827), James Watt (1736-1819), and others. Clinical bedside medicine, essentially lost since the Byzantine and Islamic era, was reintroduced by Thomas Sydenham (1624-1689), William Cullen (1710-1790), and Herman Boerhaave (1668-1738). With bedside examination came a number of original and new diagnostic examination tools. Of particular note are the contributions of Leopold Auenbrugger (1722-1809) and his introduction of percussion of the chest; William Withering (1741-1799) and his pharmacologic introduction of the use of digitalis for cardiac problems; and Edward Jenner (1749-1823), who helped eliminate a world scourge by inventing the vaccine against smallpox. In the emerging field of neurosurgery, a number of surgeons were trying to bring some sense to the management of head injury. For the first time, the focus for the surgeon was switching from the skull to the brain. This new direction and change in the neurological status of the patient marked a major paradigm shift that represented a very important step toward the origins of a separate surgical discipline of neurosurgery:

*Judgment in distinguishing, and ability in treating diseases, are not to be attained by a transient cursory view of them; merely running round an Hospital for a few months, or reading a general system of surgery, will not form a compleat practitioner: the man, who aims at that character, must take notice of many little things, which the inattentive pass over, and which cannot be remarked by writers; he must accustom himself to see, and to think for himself; and must regard the rules laid down by authors, as the outlines only of a piece, which he is to fill up and finish: books may give general ideas, but practice, and medication, must make him adroit and discerning; his reading may possibly keep him clear of very gross blunders, but he will still remain injudicious, and inexpert."

In this period, one of the most accomplished physicians was clearly Percivall Pott (1714-1788), considered by many historians to be the greatest English surgeon of the 18th century. His list of contributions, several of which apply to neurosurgery, is enormous. In his work *Remarks on That Kind of Palsy of the Lower Limbs Found to Accompany a Curvature of the Spine*, he described the disease entity now known as Pott's disease (i.e., tuberculous caries of the spine). His clinical descriptions clearly describe the gibbus and tuberculous infection of the spine. Surprisingly, Pott failed to associate the relationship between the deformity and paralysis. An osteomyelitic infection of the scalp and skull in which pus collects under the pericranium is now called Pott's puffy tumor: Pott strongly argued that these lesions should be opened and drained (Fig. 1-46). Eighteenth-century surgeons generated much discussion over the surgical practice of trephination. Pott was a strong proponent of intervention. In his classic work on head injury, he clearly appreciated the observation that clinical findings of head injury resulted from injury of the brain and not of the skull. Pott studied head injuries and began to differentiate between compression and concussion injuries of the brain. The following...
Le Dran was both an anatomist and a surgeon who developed a large surgical experience by serving as the chief surgeon to the French Army. Le Dran established a very popular school of anatomy in Paris, attracting students from all over Europe. His text Observations de Chirurgie reveals a skilled surgeon with a wide variety of surgical talents. This work became Le Dran’s most popular surgical text, being reprinted several times and translated into English in 1749. It contained a broad review of surgery, but of most importance to neurosurgeons are his views on surgery of the head. Le Dran detailed the concept of the “lucid interval” after a head injury and then attributed its aftermath most commonly to epidural hematomas (Fig. 1-47).

A remarkable and talented physician in English medicine and surgery and a student of Percivall Pott was John Hunter (1728-1793). Many writers consider Hunter equally as skilled as Pott, but his additional work in anatomy, pathology, physiology, and surgery helped him make a number of important contributions. Hunter, often referred to as the founder of experimental and surgical pathology, spent the main part of his career at St. George’s Hospital in London. Hunter was trained in the apprentice style of learning and had minimal formal education. He began his training under his older brother, William Hunter (1718-1783), and spent time with William Cheselden (1668-1752), two clearly talented teachers. As a surgeon, Hunter was clearly atypical for his time in that he approached the field of surgery in a more practical manner and at the same time added a benchside experimental touch. His A Treatise on the Blood, Inflammation, and Gun-shot Wounds was based on his years of military experience and was an important work on management of gunshot wounds.

Hunter did not offer much on neurosurgery; the section on skull fractures took up only one paragraph and is quite limited. In understanding vascular disorders, however, Hunter was insightful and innovative by describing the concept of collateral circulation. These circulation studies were conducted on a buck whose carotid artery he tied off to see the effect on the antler; no ill effect was noted, and the response was development of collateral circulation. Hunter later applied these concepts to the treatment of popliteal aneurysms, previously treated by amputation; he tied off the artery and realized that collateral circulation would develop. In Hunter’s view, a patient’s leaving the operating room a “cripple” was clearly not a good outcome. Hunter was adroit at posing questions raised by his clinical experiences, performing animal experiments to answer the questions and integrating his clinical and scientific results into the best available treatment. Hunter anatomically dissected an interesting case of craniopagus parieticus, a set of twins from India of whom one was fully formed and the other twin’s body consisted of only the head. The incomplete twin would express emotion and move the lips and mouth during eating (Fig. 1-48).

Hunter is also remembered as a devoted student of anatomic curiosities and would go to great lengths, sometimes nefariously, to obtain specimens. The most famous case was the Irish giant Charles Byrne, whom Harvey Cushing (1869-1939) later determined had acromegaly. Byrne knew of Hunter’s interest in him and went to great lengths to avoid his laboratory after death. Byrne was not successful; his skeleton became part of the Hunterian museum, which contains more than 13,000 specimens and is now part of the Royal College of Surgeons pathologic collection, a direct donation by Hunter.

A student of Hunter was John Abernethy (1764-1831), also a talented anatomist and surgeon. Abernethy is remembered for publishing the first book in America devoted to a neurosurgical topic. So popular was Abernethy as a lecturer that the governors of St. Bartholomew’s Hospital built an anatomic theatre for him, a place of training sought out by brilliant students of the period. Abernethy eventually went back to Scotland, his country of birth, and settled in Edinburgh to establish a general practice. He continued to develop a large apprenticeship program, which

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**Figure 1-46. Trephination instrumentation as designed by Percivall Pott.** The left and right illustrations are of the tripod-style instrument, with a center pin that could be driven into the fracture. The legs were often quite ornate in style. The center illustration is of a lever and screw-style instrument. The screw was driven into the fracture, and the lever arm was used to elevate the depressed bone. (From Pott P. Observations on the Nature and Consequences of Wounds and Contusions of the Head, Fractures of the Skull, Concussions of the Brain. London: C. Hitch and L. Hawes; 1760:x-xi. Courtesy James Tait Goodrich, MD, PhD.)

Clinical description from his book on head injury outlines some of his views:

The reasons for trepanning in these cases are, first, the immediate relief of present symptoms arising from pressure of extravasated fluid; or second, the discharge of matter formed between the skull and dura mater, in consequence of inflammation; or third, the prevention of such mischief, as experience has shown may most probably be expected from such kind of violence offered to the last mentioned membrane....

In the...mure fracture without depression of bone, or the appearance of such symptoms as indicate commotion, extravasation, or inflammation, it is used as a preventive, and therefore is a matter of choice, more than immediate necessity.

Pott clearly developed his outstanding reputation by his astute clinical observations and bedside treatment. Because of his aggressive management of head injuries, he is considered the first of the modern neurosurgeons. His caveats, presented in the preface to his work on head injury, are still pertinent today.

The most significant development in 18th-century writings on neurosurgical topics was the gradual recognition of the effects of trauma on brain function in addition to the skull. Several French surgeons drew a clear-cut distinction between the loss of consciousness accompanying a blow to the head and the drowsiness that appeared later. The former came to be recognized as a direct result of cerebral concussion, and the latter, after a lucid interval, came to be accepted as being caused by a collection of blood that produced compression of the brain. This idea was introduced by Jean Louis Petit (1674-1750), the leading surgeon in Paris in the first half of the 18th century, in a series of lectures that he gave in Paris. The realization that a delayed loss of consciousness could serve as an indication for surgical intervention, a direct donation by Hunter.

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attracted students from far and wide. His contributions to neurosurgery included one of the earliest treatments of neuralgia of the arm; he performed a neurectomy in 1793, which provided instant relief to the patient. Later the patient went on to regain sensation in the hand, which showed that there had been successful reunion of the nerve. Abernethy was an early advocate of ligating the common carotid artery for a cerebral hemorrhage. He later published his writings on the brain in an important work called *Pathological and Practical Researches on Diseases of the Brain and Spinal Cord.* This work contains more than 150 cases of various neurological and neuropathologic conditions that affected, the brain, spinal cord, and peripheral nerves (Figs. 1-49 and 1-50).

A contemporary of Abernethy was Benjamin Bell (1749-1806), among the most prominent and successful surgeons in 18th-century Edinburgh. Bell was a compassionate surgeon and among the first to emphasize the importance of reducing pain during surgery. Bell published a popular textbook of surgery, *A System of Surgery.* This book was widely read because of its clarity and precision in style of writing. The section on head injury contains an interesting and important discussion on the differentiation of concussion, compression, and inflammation of the brain, each necessitating different modes of treatment. Bell was a remarkably aggressive surgeon for conditions of the brain; he stresses the importance of relieving compression (i.e., trephination) of the brain, whether it is caused by a depressed skull fracture or by pus or blood. The concept of an epidural hematoma and its symptoms were appreciated by Bell; he argued for a rapid and prompt evacuation:

Affections of the Brain from external violence, often induce a very complicated set of symptoms; are attended with imminent danger, and give much embarrassment to practitioners: Accordingly, both with respect to the hazard with which they are attended, and the difficulty that we meet with in the cure, there is perhaps no class of diseases to be compared with them. Wounds and bruises of the head, which at first exhibit no marks of danger, often induce a train of symptoms which elude the skill of the most experienced practitioner; and, without admitting of any mitigation, proceed to a fatal period, ending only the death of the patient.

*A System of Surgery, Volume 3, Chapter X, Section 1*
His description of the symptoms of brain compression from external violence is classic:

A great variety of symptoms…indicating a compressed state of the brain [with]…the most frequent, as well as the most remarkable, are the following: Giddiness; dimness of sight; stupefaction; lots of voluntary motion; vomiting; an apoplectic stertor in the breathing; convulsive tremors in different muscles; a dilated state of the pupils, even when the eyes are exposed to a clear light; paralysis of different parts, especially of the side of the body opposite to the injured part of the head; involuntary evacuation of the urine and feces; an oppressed, and in many case an irregular pulse....

_A System of Surgery, Volume 3, Chapter X, Section III_109

Bell was among the first to note that hydrocephalus was often associated with spina bifida. His treatment of a myelomeningocele involved placing a ligature around the base of the myelomeningocele sac and slowly cinching it down until it was allowed to slough off. Bell also noted that outcomes in these cases were almost always poor. The thoroughness and clarity of Bell’s writings on the brain demonstrate why it was one of the most important and popular surgical works in this era.

In 1709 a small and now rare monograph was authored by Daniel Turner (1667-1741)110: A Remarkable Case in Surgery: Wherein an Account Is Given of an Uncommon Fracture and Depression of the Skull, in a Child About Six Years Old; Accompanied with a Large Abscess or Aposteme upon the Brain.... This monograph provides a contemporary view of an 18th-century surgeon and the concerns of trephining the brain (Fig. 1-51).

Turner’s case is most disturbing to read because it is written in the frank and somewhat verbose style of this period. Turner was “…called in much hast, to a Child about the Age of Six Years,…wounded by a Catstick (thrown by a youth who missed
his aim) unfortunately struck the Child over the Head, and knock’d him down. He was taken up for dead and continued speechless for some time.” On examination of the head, Turner found a considerable depression and believed that the child was in great danger. He sent for the barber to shave the child’s head; while waiting for the barber, he performed a common practice by opening a vein in the arm to bleed the child, taking about 6 oz. The patient regained consciousness, complaining of a headache, but no vomiting. He was very sensible.” Turner visited the child the following day and found him still feverish but without other symptoms. He removed the dressings and realized the extent of the fracture, which he now realized had been only partially elevated. Turner pulled out a trephine, surveyed the situation, and decided where it was safest to trephine. He removed the dressings and realized the extent of the fracture and the elevation of the injury as described in the text. (From Turner D. A Remarkable Case in Surgery: Wherein an Account Is Given of an Uncommon Fracture and Depression of the Skull, in a Child About Six Years Old; Accompanied with a Large Abscess or Aposteme upon the Brain. With Other Practical Observations and Useful Reflections Thereupon. Also an exact Draught of the Case, Annex’d. And for the Entertainment of the Senior, but Instruction of the Junior Practitioners, Communicated. London: R. Parker; 1709 [see p. 52 in Turner110 for quotation]. Courtesy James Tait Goodrich, MD, PhD.)

Figure 1-51. An illustration from Daniel Turner’s book, A Remarkable Case in Surgery.... In this book, Turner demonstrated the skull fracture and the elevation of the injury as described in the text. (From Turner D. A Remarkable Case in Surgery: Wherein an Account Is Given of an Uncommon Fracture and Depression of the Skull, in a Child About Six Years Old; Accompanied with a Large Abscess or Aposteme upon the Brain. With Other Practical Observations and Useful Reflections Thereupon. Also an exact Draught of the Case, Annex’d. And for the Entertainment of the Senior, but Instruction of the Junior Practitioners, Communicated. London: R. Parker; 1709 [see p. 52 in Turner110 for quotation]. Courtesy James Tait Goodrich, MD, PhD.)

Figure 1-52. The title page from the first American textbook printed on surgery in the American Colonies. This book became the handbook for American Revolutionary War surgeons. (From Jones J. Plain Concise Practical Remarks, on the Treatment of Wounds and Fractures; to Which is Added, An Appendix, on Camp and Military Hospitals; Principally Designed, for the Use of Young Military and Naval Surgeons, in North-America. Philadelphia: Robert Bell; 1776 [Original work published 1775]. Courtesy James Tait Goodrich, MD, PhD.)

An American surgeon who made an interesting contribution to neurosurgery was John Jones (1729-1791). In what is now a rare monograph, published in New York in 1776, this Revolutionary War–era surgeon provided the first American textbook on surgery.111 Jones was educated in Europe; studied under Pott, Hunter, Alexander Monro, Petit, and Le Dran; and carried this education back to the United States. Jones was among the physicians to form the first medical school in America, the University of Pennsylvania, in Philadelphia. Jones was also one of the founders of New York Hospital. Jones’s monograph on surgery became the handbook of surgery for Revolutionary War surgeons. His views and techniques on trephination clearly reflect the views of his European teachers, especially Pott, Le Dran, and Petit (Fig. 1-52).

In Europe, a number of important people were refining the art and skills of surgery. These physicians were important in leading surgical treatment away from the more common itinerant charlatan and barber-surgeon, most of whom were ignorant charm and relic dispensers. One of the most popular surgical textbooks of this century was published by a German surgeon, Lorenz Heister (1683-1758). Heister was educated as both a surgeon and an anatomist, which is now common. Heister began his lectures in Latin, but because his students were so uneducated, he changed to German. Heister went on to publish his first textbook in German.112 The text was so popular that it was subsequently translated into a number of languages, including English, and circulated widely in Europe and England.113 Because it concluded “That wounds of the brain, are not always mortal” (see page 52 in Turner110).
An early and successful treatment of a brain abscess was accomplished by Sauveur-François Morand (1697-1773). Morand's patient, a monk, developed an otitis and subsequently mastoiditis, which led to a temporal brain abscess. Morand trephined over the carious bone and discovered pus. He then placed a catgut wick into the open surgical wound, but it continued to drain. He reopened the wound, this time performing a very adventurous maneuver of opening the dura through a cruciate incision, and found a brain abscess. He explored the abscess with his finger, removing as much of the contents as he could, and then instilled balsam and turpentine into the cavity. He placed a silver tube for drainage, and as the wound healed, he slowly withdrew the tube. The abscess healed, the patient survived, and Morand reported this case as a successful treatment of a brain abscess.

The Neapolitan physician Domenico Cotugno (1736-1822) published a monograph of only 100 pages, De Ischiade Nervosa Commentarius, which contains the first classic descriptions of cerebrospinal fluid and sciatica. Cotugno performed a number of experiments on the cadavers of approximately 20 adults. Using a lumbar puncture technique, he was able to demonstrate the characteristics of cerebrospinal fluid. In De Ischiade Nervosa Commentarius, Cotugno demonstrated the “nervous” origin of sciatica, differentiating it from the then-common view that sciatica was secondary to arthritis. Cotugno was the first to describe cerebrospinal fluid and the first to demonstrate the “nervous” origins of sciatica, illustrating these concepts in a nine-page manuscript that was never published. Cotugno was the first to outline the pathways of cerebrospinal fluid, showing that it circulated in the pia-arachnoid interstices and flowed throughout the brain and spinal cord via the aqueduct and convexities. Cotugno also described hydrocephalus ex vacuo, the type of hydrocephalus that occurs in cerebral atrophy.

Heister popularized a number of techniques that proved helpful to contemporary surgeons. To control scalp hemorrhage, he used a “crooked needle and thread” that was weaved in and out of the scalp and then drawn tight. An astute observer, Heister pointed out that when the assistant applied pressure to the skin edge, bleeding could be markedly reduced. Heister's management of spinal injuries was aggressive: he would operate, expose the fractured vertebra, and then remove the fragments that had damaged the spinal marrow; he recognized that grave outcomes of such attempts were not uncommon and that the surgeon should be prepared for that.
A popular and skilled French military surgeon was Louis Sébastien Saucerotte (1741-1814) (also listed as Nicolas). Saucerotte was at one time surgeon to the King of Poland and then a military surgeon in various French Army units. As has often been the case in the history of neurological surgery, the occasion to deal with war injuries provided the most training and insight into the management of head injury. Saucerotte reintroduced the concept of the contrecoup injury, lost since antiquity. In his surgical textbook *Mélanges de Chirurgie*, he described a series of intracranial injuries and their symptoms, including compression of brain as a result of blood clot. Saucerotte described a classic case of ataxia caused by a cerebellar lesion, whose symptoms included opisthotonus and rolling of the eyes. Saucerotte divided the brain into “areas” of injury, pointing out that injury at the base of the brain produces the most severe debilitation, whereas injuries of the forebrain are the best tolerated. Saucerotte also contributed one of the earliest clinical descriptions of acromegaly.

The close of the 18th century brought some remarkable change in philosophy about surgery of the brain. Surgeons’ management of head injury became much more aggressive. Clinical symptoms associated with brain injury were better recognized. Anatomic concepts such as the circulation of cerebrospinal fluid were better understood. What surgeons still lacked was a better understanding of cerebral localization, methods to treat surgical infection, and the ability to provide insensibility to pain during surgery. The role of trephination for head injuries was being fiercely debated in the surgical literature. There was a backlash because of the inability of surgeons to distinguish between the lack of efficacy of the operation and the introduction of infection by a surgical procedure. As a result of iatrogenic infection, the outcomes often seemed better without surgery than with intervention, especially if a surgical infection developed. The developments of the 19th century included cerebral localization, anesthesia, and antisepsis, all critical in the origins of modern neurosurgery.

NINETEENTH CENTURY: INCUNABULA PERIOD OF MODERN NEUROSURGERY

Modern neurosurgery began with three important developments that occurred in the 19th century. The first was the introduction of anesthesia, which provided patients freedom from pain during surgery. The second was the introduction of cerebral localization (neurological signs and symptoms), which helped surgeons establish diagnoses and plan their operative approach. The third was the introduction of antisepsis and aseptic technique, which enabled the surgeon to operate with a reduced risk of perioperative complications resulting from infection.

A noted medical and surgical expert in this period was Sir Charles Bell (1774-1842), a Scottish surgeon and anatomist. Bell was educated at the University of Edinburgh and spent most of his professional career in practice in London. Bell is remembered for his many contributions to the neurosciences, including the differentiation of the motor and sensory component of the spinal root. Bell wrote a number of works on surgery, many of which were illustrated with his own drawings. These surgical drawings remain unrivaled in detail, accuracy, and beauty (Figs. 1-55 and 1-56).

If a drawing of all that we see in an operation, be an imperfect demonstration, so is the lesson of an operation performed on the dead body imperfect, for the circumstances most essential to know, cannot be presented there: so is the actual operation on the living body an imperfect demonstration, from the partial and rapid view which the spectator obtains. And, finally, as to description, words alone will never inform the young Surgeon of the things most necessary to a safe operation.

Bell provided a skillful contemporary account of a trephination technique as practiced in 1821:

Let the bed or couch on which the patient is lying be turned to the light—have the head shaved—put a wax-cloth on the pillow—let the pillow be firm, to support the patient’s head. Put tow [sic] or sponge by the side of the head—let there be a stout assistant to hold the patient’s head firmly, and let others put their hands on his arms and knees.

The surgeon will expect the instruments to be handed to him in this succession—the scalpel; the rasparatory; the trephine; the brush, the quill, and probe, from time to time; the elevator, the forceps, the lenticular.

Combined with his detailed description of trephination is a discussion of techniques and pitfalls to avoid. The hand-colored illustrations that accompany the text are quite dramatic in detail and are designed to assist the surgeon in mastering the technique.
Bell’s work is an important work in providing illustrations of detailed neurosurgical technique.

Over the previous centuries, surgeons had tried various methods of reducing sensitivity to pain, with minimal success. Mandrake, Cannabis, opium and other narcotics, the “soporific sponge” (saturated with opium), and alcohol had all been tried. In 1844, Horace Wells (1815-1848), a dentist in Hartford, Connecticut, introduced the use of nitrous oxide in dental procedures, and for the first time, a good anesthetic result was achieved.120 Unfortunately, the death of one of his patients from what was probably an overdose of the anesthetic stopped him from investigating further. In Boston, another early investigator, William T. G. Morton (1819-1868), also introduced an early collaborator with Wells, persuaded a surgeon, Dr. John C. Warren (1778-1856), to use ether to induce anesthesia. On October 16, 1846, Warren did so and produced a state of insensibility in a patient, during which a vascular tumor of the submaxillary region was removed.121

In the United Kingdom another surgeon, James Young Simpson (1811-1870), was using another agent called chloroform that had just been introduced in 1847 as an anesthetic agent.122 The contemporary literature was full of arguments then being pursued regarding the issue of which was the best agent. Morton turned out to be quite bold by patenting the ether technique and then asking the U.S. Congress for compensation for his discovery of ether and its use in surgery. Politics aside, the result of all of this research was the first opportunity for a surgeon to operate on a patient without the need for heavy restraints on the patient or for the physician to operate at unsafe speed. As a result, patients gained freedom from pain during the procedure, along with a new lack of fear of surgery—developments whose importance cannot be underestimated in a surgery practice and particularly in the treatment of brain lesions.

Early surgeons approached either a skull or brain injury with great trepidation. Even with the best of surgical technique, patients often died postoperatively of suppuration and infection. Fears, purulent material, brain abscess, and draining wounds all defeated the best surgeons. No surgeon could hope to invade or open the dura mater without inviting disaster until the risk of operative infection could be reduced. The first significant change came about when Sir Joseph Lister (1827-1912), using concepts developed by medical practitioners, introduced antisepsis in the operating room.123,124 In a different operating arena, Oliver Wendell Holmes, Sr. (1809-1894), and Ignaz G. Semmelweis (1818-1865) first showed that it was the contaminated hands of the obstetrician that spread puerperal fever, a devastating infection for women during delivery.125,126 Holmes and Semmelweis strongly argued for hand washing between cases, a concept that became bitterly debated at the time. To provide a contrast, it is strongly argued for hand washing between cases, a concept that along with a new lack of fear of surgery—developments whose importance cannot be underestimated in a surgery practice and particularly in the treatment of brain lesions.

Sir Jonathan Hutchinson (1828-1913) provided an important chapter in the acceptance of neurological signs and symptoms as indicators for surgical intervention. In 1867, the same year that Lister published his first papers on the role of antisepsis in surgery, Hutchinson published a series of papers on brain compression that introduced a new diagnostic sign for head injury.134 His recognition of third nerve paralysis remains one of the most useful signs for head injury and increased intracranial pressure. Coupled with the recognition of a lucid interval after head trauma, it provided an important neurological sign to enable surgeons to recognize the need for trephining. Hutchinson also argued that a pupil that was fixed and dilated was likely to indicate the side of the hematoma. For the first time in 350 years, since a 16th century artist (Gerzdorf, 151719) recorded this observation, the mechanism and significance of this finding was established.

Hutchinson wrote as follows134:

…from the position of the clot there can be little doubt that the third nerve is compressed and thus, the dilatation of the pupil is explained. These two cases, so exactly parallel, seem to supply us with a new and very valuable symptom indicative of effusion of blood in this situation.

He went on modestly to note,

…nor can we boast of having learnt much which may aid us in the diagnosis of future cases, with the one exception of having discovered the meaning of the one dilated pupil. This point we will store up carefully for future use.”134

Sir Rickman J. Godlee (1849-1925) performed one of the most celebrated operations, the removal of a brain tumor, the first to be successfully diagnosed by cerebral localization in 1885.135 The patient had suffered for 3 years from focal motor seizures. They started as focal seizures of the face and proceeded to involve the arm and then the leg. In the 3 months before
William R. Gowers was one of an extraordinary group of English neurologists of that era. Using some of the recently developed techniques in physiology and pathology, he made great strides in refining the concept of cerebral localization. Gowers was noted for the clarity and organization of his writing, works that remain classics in the field. Studies such as these allowed surgeons to consider operating on the central nervous system for nonheroic reasons. Godlee and Horsley were trained general surgeons who had both the ambition and fortitude to consider surgically exploring the central nervous system now that our neurology colleagues could localize the tumors.

The successful removal of a spinal tumor brought Horsley to the forefront in the development of neurosurgery during its birthing period. Horsley began his experimental studies on the brain in the early 1880s, at the height of the cerebral localization controversies. Using faradic stimulation, he worked with Sir Edward A. Sharpey-Schafer (1850-1935) in analyzing and localizing motor functions in the cerebral cortex, internal capsule, and spinal cord of primates. In a classic study (Croonian Lectures 1891) performed with his brother-in-law, Francis Gotch (1853-1913), Horsley, using a string galvanometer, showed that electrical currents originate in the brain. These electrical currents were propagated from the brain out through the nerves. These intraoperative experimental studies showed Horsley that localization was possible and that operations on the brain could be conducted safely with techniques adapted from general surgery.

Horsley was a very fast and deft surgeon, typically performing the most complex surgeries in less than 40 minutes. He carried surgery, the patient also developed weakness and eventually had to give up his work. Working with a neurologist, Alexander H. Bennett (1848-1901), Godlee was able to localize the tumor and remove it. This case was an important landmark in neurosurgery. For the first time, a neurologist, basing his conclusions on the findings from a neurological examination, localized a brain tumor and enabled it to be removed surgically. Godlee made an incision over the Rolandic area, and through a small cortical incision, the tumor was removed. The patient survived the surgery with some mild weakness and did well, only to die 1 month after surgery from a wound infection. Added to the importance of the surgery itself was the presence in the operating room of three important scholars: A. Hughes Bennett, a prominent English physician, and the two neurologists J. Hughlings Jackson and David Ferrier. These men were extremely interested in whether the cerebral localization studies were to provide good results in the operating theatre. This operation was the impetus that truly moved neurosurgery forward (Fig. 1-57).

Three years later, in 1888, Victor Horsley (1857-1916) performed the first removal of a spinal cord tumor that had been diagnosed and localized by William R. Gowers (1845-1915). Horsley performed a laminectomy on Gowers's patient, Captain Golby. Golby was slowly losing function in his legs as the result of a spinal cord tumor. Gowers localized the tumor by examination and suggested to Horsley where to operate; the tumor was successfully removed. A postoperative photograph of the patient with a healed midline thoracic scar is included in the original paper (Fig. 1-58).

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a trunk full of surgical instruments, sterilized the night before at his home. The surgery was often performed in the bedroom of the patient.

Horsley made a number of technical contributions to neurosurgery, including the use of beeswax to stop bone bleeding.\cite{141,142} He performed one of the earliest operations for craniosenosis and relief of increased intracranial pressure. The patient, a child, had a premature closure of the anterior fontanelle. The child survived and went on to serve in World War I. For trigeminal neuralgia, Horsley pioneered the technique of sectioning the posterior root of the trigeminal nerve for pain relief, the first effective treatment for this relentless condition.\cite{143} Using his technical gifts, he helped Robert H. Clarke (1850-1926), a physiologist, design the first useful stereotaxic apparatus for brain surgery. The apparatus was designed to localize a series of numerical coordinates (three-dimensional cartesian coordinates) associated with specific areas of the brain. In the original description, the authors coined the term \textit{stereotaxis}, which is derived from the Greek \textit{steros}, meaning “three-dimensional,” and \textit{taxis}, which refers to an “an order or arrangement.” Although this apparatus was used only on animals, the Horsley-Clark stereotaxic frame remains the standard concept on which all subsequent stereotactic designs/frames have been based\cite{144} (Fig. 1-60).

At the age of 59, with the onset of World War I, Horsley was sent to Amara, Mesopotamia (Iraq), to help develop hygienic procedures in a desert outpost. Ironically, he died within 2 days of arrival after contracting a severe desert fever (reported outside temperature, 120° F), an early tragic loss of a brilliant mind and surgeon. Horsley was one of those talented scholars who were able to combine experimental research with clinical practice and in turn provided remarkable advances in neurosurgery.

\textbf{William Macewen} (1848-1924), a Scottish surgeon and pioneer in the field of neurosurgery, successfully accomplished one of the early brain operations on July 29, 1879.\cite{145} Macewen operated on a 14-year-old patient, removing a periosteal tumor over the right eye. Using meticulous technique and the recently developed neurological examination, he localized the tumor and removed it. The patient lived 8 years afterwards, only to die of Bright’s disease; at autopsy, no tumor was detected. By 1888, Macewen had operated on 21 neurosurgical cases with only 3 deaths and 18 successful recoveries: a remarkable turnaround from earlier studies. Macewen’s monograph, published in 1893, on pyogenic infections of the brain and their surgical treatment represented a revolution in neurosurgery.\cite{146} This monograph was the earliest to deal with the successful treatment of brain abscess. His morbidity and mortality statistics, reflecting the application of localization techniques and effective antisepsis, were not inferior to those in any series reported today. Without good surgical results, neurologists of that era were hesitant to recommend surgery; Macewen helped immensely to make the case for soundly conducted operations on the brain (Figs. 1-61 and 1-62):

\begin{quote}
Though not sharing the hopelessness of the opinion expressed in 1883 by a distinguished neurologist as to the inutility of operations on the brain undertaken for abscess, the author was then inclined to take a more sombre view of the prospects of recovery from such operations than his subsequent experience has proven to be necessary. He now regards an uncomplicated cerebral abscess, early recognized, accurately localized, and promptly operated on, as one of the most satisfactory of all intracranial lesions, the patient being at once relieved from a perilous condition, and usually restored to sound health.
\end{quote}

\textit{—from the Preface to Pyogenic Infections}\cite{146}

The concept of “early recognized, accurately localized, and promptly operated on” is still a fundamental concept for neurosurgeons.
In the United States, among the earliest pioneers in neurosurgery was William W. Keen (1837-1932), professor of surgery at Jefferson Medical College in Philadelphia. Keen was one of the strongest American advocates for the use of the recently introduced Listerian antiseptic techniques in surgery. The concept of surgical bacteriology, along with those of asepsis and antisepsis, was aggressively discussed in his writings. Keen was one of the earliest American monographs on neurosurgery was prepared by Keen, a book called Linear Craniotomy. He developed a technique for treatment of spastic torticollis by division of spinal accessory nerve and posterior roots of the first, second, and third spinal nerves. For treatment of the excoriating pain associated with trigeminal neuralgia, he devised a technique for resection of the gasserian ganglion. Keen exercised a rare inventiveness in surgical technique: he used bent spoons from his kitchen to act as brain retractors. Keen was also the first to introduce the Gigli saw to American surgeons, an important technical advance in performing a craniotomy (Figs. 1-63 and 1-64).

Figure 1-61. William Macewen. Macewen developed sterile surgical techniques that remained among the best in the literature for nearly 50 years. (Courtesy James Tait Goodrich, MD, PhD.)

Figure 1-62. William Macewen in the operating room. He is the bearded gentleman on the patient’s right side, surrounded by his staff. Although not gloved and masked, they were using sterile principles in the operating room, including the Lister carbolic sprayer, clean gowns, and clean hands. (Courtesy James Tait Goodrich, MD, PhD.)

Figure 1-63. Title page of William W. Keen’s paper on the treatment of microcephalus. Keen was one of the great pioneers in early American neurosurgery and is little recognized today. An early advocate of Listerian aseptic techniques, he made some important contributions to surgery, particularly in neurosurgery. One of the earliest techniques developed for multiseptur craniosynostosis is discussed in this paper. (From Keen WW, Linear Craniotomy. Philadelphia: Lea Bros. and Co.; 1891 [Original work published 1890]. Courtesy James Tait Goodrich, MD, PhD.)

Figure 1-64. William W. Keen in the operating room with his surgical team. Note Keen’s “bloody” ungloved hands and the lack of mask and head covering. (Courtesy James Tait Goodrich, MD, PhD.)
A professor of surgery in Berlin, Fedor Krause (1857-1937), was a general surgeon who developed a keen interest in neurosurgery. Krause's three-volume atlas on neurosurgery, published in the first decade of the 20th century, was among the first surgical textbooks to provide detailed illustrated techniques of neurosurgery. Digital extirpation of a meningioma is graphically described. A number of neurosurgical techniques are reviewed, including resection of scar tissue for treatment of epilepsy. Krause was an early pioneer in the extradural approach to the gasserian ganglion for treatment of trigeminal neuralgia (Figs. 1-65 and 1-66).

The first American monograph devoted solely to brain surgery was written, not by a neurosurgeon, but by a New York neurologist, Moses Allen Starr (1854-1932). Starr was Professor of Nervous Diseases at Columbia and an American leader in the field of neurology. He trained in Europe, working in the laboratories of Wilhelm Erb, Friedrich Schultze, Theodor Meynert, Hermann Nothnagel, Jean-Marie Charcot, and Sigmund Freud. These experiences provided him with a strong foundation in neurological diagnosis (Fig. 1-67). Starr was present at the 1888 Congress of American Physicians and Surgeons when David Ferrier and Victor Horsley presented a symposium dealing with recent findings on the cerebral localization of brain function. In the late 1880s, Starr began working closely with Charles McBurney (1845-1913), a general surgeon in New York City, and the two became important collaborators. Starr realized quickly that brain surgery not only could be performed safely but was clearly necessary in treatment of certain neurological problems. Before this collaboration, the only brain surgeries being performed in New York were cases of visible tumors and injuries of the scalp and skull, such as a fungating tumor of the skull or a depressed skull fracture. Of interest is that McBurney performed the first antiseptic surgical procedure in the United States at the Presbyterian Hospital in New York City in 1876. Starr's book describes cases involving epilepsy, hemorrhage, abscess, and tumors (see Fig. 1-67).

Starr summarized his views in the preface of his book on Brain Surgery:

Brain surgery is at present a subject both novel and interesting. It is within the past five years only that operations for the relief of epilepsy and of imbecility, for the removal of clots from the brain, for the opening of abscesses, for the excision of tumors, and the relief of intra-cranial pressure have been generally attempted…

Brain surgery has as its essential basis the accurate diagnosis of cerebral lesions, which was impossible until the localization of cerebral functions had been determined. And this diagnosis must be made by the physician before the surgeon is called in to remove the disease. It is the object of this book to state clearly those facts regarding the essential features of brain disease which will enable the reader to determine in any case both the nature and situation of the pathological process in progress, to settle the question whether the disease can be removed by surgical interference, and to estimate the safety and probability of success by operation. The facts have been reached by a careful study of the literature of the subject and by a considerable personal experience… It is my hope that this work may aid the physician to diagnosticate brain diseases with more accuracy, and to select such cases as are properly open to surgical treatment by trephining, and also that may enable the surgeon to perform his delicate task with more precision and with a fuller knowledge of those principles of local diagnosis which should form this constant guide.

Figure 1-65. One of the earliest cerebellopontine angle approaches for removing an acoustic neuroma. Both the surgical approach and the anatomy of the tumor in relation to the seventh and eighth cranial nerves are clearly outlined in the image on the right. (From Krause F. Surgery of the Brain and Spinal Cord Based on Personal Experiences [Haubold H, M. Thorek M, Trans.]. New York: Rebman Co.; 19-1912. Courtesy James Tait Goodrich, MD, PhD.)

Figure 1-66. Fedor Krause’s “osteoplastic” flap technique. Krause was a firm advocate of this technique, in which the craniotomy was elevated with the overlying muscle and scalp. Krause performed a unilateral craniotomy to expose the cerebellum (A and B). On reaching the tumor, Krause removed it (C) by taking his index finger and scooping the tumor out. (From Krause F. Surgery of the Brain and Spinal Cord Based on Personal Experiences [Haubold H, Thorek M, Trans.]. New York: Rebman Co.; 19-1912. Courtesy James Tait Goodrich, MD, PhD.)
Harvey William Cushing (1869-1939) was the founder of American neurosurgery. Cushing had the good fortune to be alive and in training during the formative years of neurosurgery. Trained at Johns Hopkins Hospital by one of the premier general surgeons, William Halsted (1852-1922), Cushing learned meticulous surgical technique from his mentor. As was standard then, Cushing spent time in Europe; he worked in the laboratories of Emil Theodor Kocher (1841-1917) in Bern, Switzerland, investigating the physiologic properties of cerebrospinal fluid. These studies led to his important monograph in 1926 on the third circulation. It was during this period of experimentation that the cerebral phenomenon of increased intracranial pressure in association with hypertension and bradycardia was defined; it is now referred to as Cushing’s phenomenon. While traveling through Europe, he met several important surgical luminaries, including William MacEwen and Victor Horsley. These individuals encouraged Cushing to consider neurosurgery as a full-time endeavor (Figs. 1-68 and 1-69).

Cushing’s contributions to the literature of neurosurgery are too extensive for this chapter. Among his most significant is a monograph on pituitary surgery, published in 1912. This monograph was to inaugurate a sterling career in pituitary studies. Cushing’s syndrome was defined in his final monograph on the pituitary gland, published in 1932. In a 1926 monograph written in collaboration with an early resident named Percival Bailey (1892-1973), Cushing brought the first rational approach to the classification of brain tumors. Before this volume, classifications of brain tumors were in a complete state of disarray and confusion. The tumors medulloblastoma and hemangioblastomas were classified and described by these two surgeons. Cushing’s monograph on meningioma, written in 1938 with Louise Eisenhardt (1891-1967), a collaborator and neuropathologist, set an extraordinarily high standard for the profession.

Cushing retired as Moseley Professor of Surgery at Harvard in 1932. By the time he completed his 2000th brain tumor operation, he had unquestionably made one of the most important
contributions to the field of neurosurgery: a contribution comprising meticulous, innovative surgical techniques and a career-long attempt to understand brain function from both physiologic and pathologic points of view. An ardent bibliophile, Cushing spent his final years in retirement as Sterling Professor of Neurology at Yale, where he wrote his extraordinary monograph on Andreas Vesalius. Cushing’s life was faithfully recorded by his close friend and colleague, John F. Fulton (1899-1960), and in a more recent biography by Michael Bliss.

If Harvey Cushing was the father of American neurosurgery, his prodigal son was Walter Dandy (1886-1946). Dandy trained under Cushing at the Johns Hopkins Hospital. He made a number of important contributions to neurosurgery. Using the serendipitous finding of Luckett, the presence of air in the ventricles after a skull fracture, Dandy developed the technique of pneumoencephalography (PEG). The introduction of PEG provided the neurosurgeon, for the first time, the opportunity to localize a tumor by analyzing the displacement of air in the ventricles. Dandy was an innovative neurosurgeon, considerably more aggressive in style and technique than Cushing. Dandy was the first to show that acoustic neuromas could be removed in their totality. The publication of this technique led to some significant and vehement clashes between Cushing and Dandy. Cushing believed that a subcapsular resection was safer and produced less morbidity (Fig. 1-70).

Dandy was a pioneer in the diagnosis and treatment of hydrocephalus. Dandy developed the technique of ablating and removing the choroid plexus to reduce the production of cerebrospinal fluid. Dandy was among the first to treat cerebral aneurysms surgically by obliterating them through the use of snare ligatures or metal clips. The concept of a postoperative “recovery room” with a specialized “brain team” originated with Dandy. This is now the accepted standard; before Dandy’s time, this was not case.

In the field of textbooks, Dandy provided some brilliantly illustrated monographs on the brain with illustrations by Dorcas H. Padget (1906-1973), a largely self-taught illustrator. Dandy’s monograph on the third ventricle and its anatomy is still a textbook standard to this day, with illustrations that remain among the finest illustrations ever produced (Fig. 1-71). In the field of spinal surgery, one important American in the first quarter of the 20th century was Charles H. Frazier (1870-1936), Professor of Surgery at the University of Pennsylvania. Work published by James L. Corning (1855-1923) in 1885 proved that lumbar puncture in both dogs and humans could be safely performed. Corning was injecting cocaine into the epidural space and providing local anesthetic via an epidural block. This procedure was popularized by Heinrich Irenaeus Quincke (1842-1922), who used it in the treatment of hydrocephalus; from this procedure, spinal surgery developed. When Charles Frazier’s book on spinal surgery appeared in 1918, it was recognized as the most comprehensive work on spinal surgery written and an important prescient work in spine surgery that set a new standard. In this work and the bibliography, Frazier summarized much of the spinal surgery literature up to the time of publication. Frazier firmly established that spinal surgery could be performed with minimal morbidity and mortality. Frazier’s

Figure 1-70. Pneumoencephalograms. One of the landmark contributions to neurosurgery was Walter Dandy’s (and Kenneth Blackfan’s) introduction of pneumoencephalography, a technique in which air was introduced into the ventricles and radiography was then used to image the ventricular system in outline. (Courtesy James Tait Goodrich, MD, PhD.)

Charles Babbage and the Concept of the Computer

If asked when the computer was invented, few individuals today would even comprehend that the origins of this technology date back approximately 200 years. The term computer was first coined in 1613, and it was used to describe a person who performed calculations or computations. In 1822, Charles Babbage (1791-1871) began developing a model of a programmable computer, but it existed only on paper. Babbage called his machine a “difference engine.” Babbage was a true polymath, skilled in mathematics, philosophy, and mechanical engineering. The machine design was created to calculate a series of values automatically through the use of computable polynomial functions. Despite superb intellectual skills, Babbage had great difficulty in landing a university position, having been turned down for academic positions a number of times. In 1828 he finally became Lucasian Professor of Mathematics at Cambridge (Trinity College), this after having been rejected for the position three times previously. Ironically, Babbage lacked interest in lecturing and teaching students and did not deliver a single lecture as a professor.

Babbage was awarded a Gold Medal by the Astronomical Society in 1824 for “his invention of an engine for calculating mathematical and astronomical tables.” The computer that Babbage proposed on paper was not to be built until 1991, when the London Science Museum constructed a functioning model from his drawings. The computer in the final design turned out to be a large and heavy machine. His basic design was a forerunner of and very similar to a modern computer. In Babbage’s design, the data and program memory were housed separately. The binary concept is not as modern people might think, inasmuch as Babbage constructed his machine with this very same computational design (Fig. 1-72). The London Museum of the
CHAPTER 1 Historical Overview of Neurosurgery

Wilhelm Röntgen and the X-Ray

Wilhelm Röntgen (1845-1923), a German mechanical engineer and physicist by training, discovered on November 8, 1895, what he would call the “x-ray.”

Röntgen was chair of the physics department at the University of Würzburg. Of interest is that at one point, he accepted an appointment at Columbia University, but the beginning of World War I prevented his coming. Röntgen was interested in the external effects of various types of vacuum tube devices. Using a cathode ray and a coil that generated an electrostatic charge, he was able to generate an x-ray image on a barium platinocyanide screen. For two intensive weeks in November 1895, Röntgen rarely left his laboratory; he performed various experiments, perfecting what he called the “x-ray.” The very first radiographs were images of the hand of his wife, Anna Bertha. Röntgen then published in rapid sequence three papers on the x-ray in 1895 and 1896. Röntgen titled his papers *Über Eine Neue Art von Strahlen* [On a New Kind of Rays] (Fig. 1-74).

Röntgen is considered the father of diagnostic radiology and for his efforts was awarded the Nobel Prize in Physics in 1901. Use of x-rays was rapidly adopted in medicine and science throughout the world. Röntgen died in 1923 from an intestinal carcinoma. Because he used lead shields routinely, it is not thought this carcinoma was caused by the radiation experiments. The effect of radiography on medicine and science was immediate, and it is now used for many different purposes, from diagnosis to medical therapeutics.

Computed Tomography

Sir Godfrey Newbold Hounsfield (1919-2004), a computer expert and engineer working at the Central Research Laboratories of EMI, developed the first computed tomographic (CT) scanner. Hounsfield initially conceptualized the use of x-rays coming from multiple directions to reconstruct the internal structure of objects being imaged. Like Charles Babbage, he

Figure 1-73. Container housing half of Charles Babbage’s brain. (From the Charles Babbage exhibit at the Science Museum in London.)

Figure 1-74. A, An offprint of Wilhelm Röntgen’s seminal paper on the discovery of the x-ray. B, A 1922 drawing of Röntgen, showing this scientist at the age of 50, when he was doing his seminal work on the x-ray. (Courtesy James Tait Goodrich, MD, PhD.)
realized he would need a computer with mathematical calculating ability that would need to be combined with the x-ray source to scan and construct the image. Housfield had no medical background training, and so this task was an enormous one. He initially developed the concept of the “slice” and of then building up a series of slices to make an image. His original machine design took 9 days to produce a single image. The first images were of “kosher-killed” beef brains. By changing the source of x-rays, he was able to develop a more efficient machine, but the image production was still extremely slow, with only a single image in a day. Work on human subjects began in 1970 at the Atkinson Morley’s Hospital in Wimbledon, England. By 1971, Hounsfield was able to produce a single scan in 4 minutes, meaning that a total study (10 scans) took 40 minutes. By converting to a more powerful computing language (FORTRAN), he was able to reduce scan times to 20 minutes. Since then, computers with better resolution and scan times have been introduced187,188 (Fig. 1-75).

As a result of their surgical forebears, neurosurgeons can now complete a neurosurgical procedure with minimal pain to the patient, along with a marked reduction in infections. The 19th-century surgeons pioneered techniques in cerebral localization, and modern neurosurgeons are even more fortunate with the introduction of frameless guidance systems. The surgical fear of operating on the wrong area should no longer be an issue, thanks to the efforts and studies of the surgical pioneers and the specialty called neurosurgery.

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