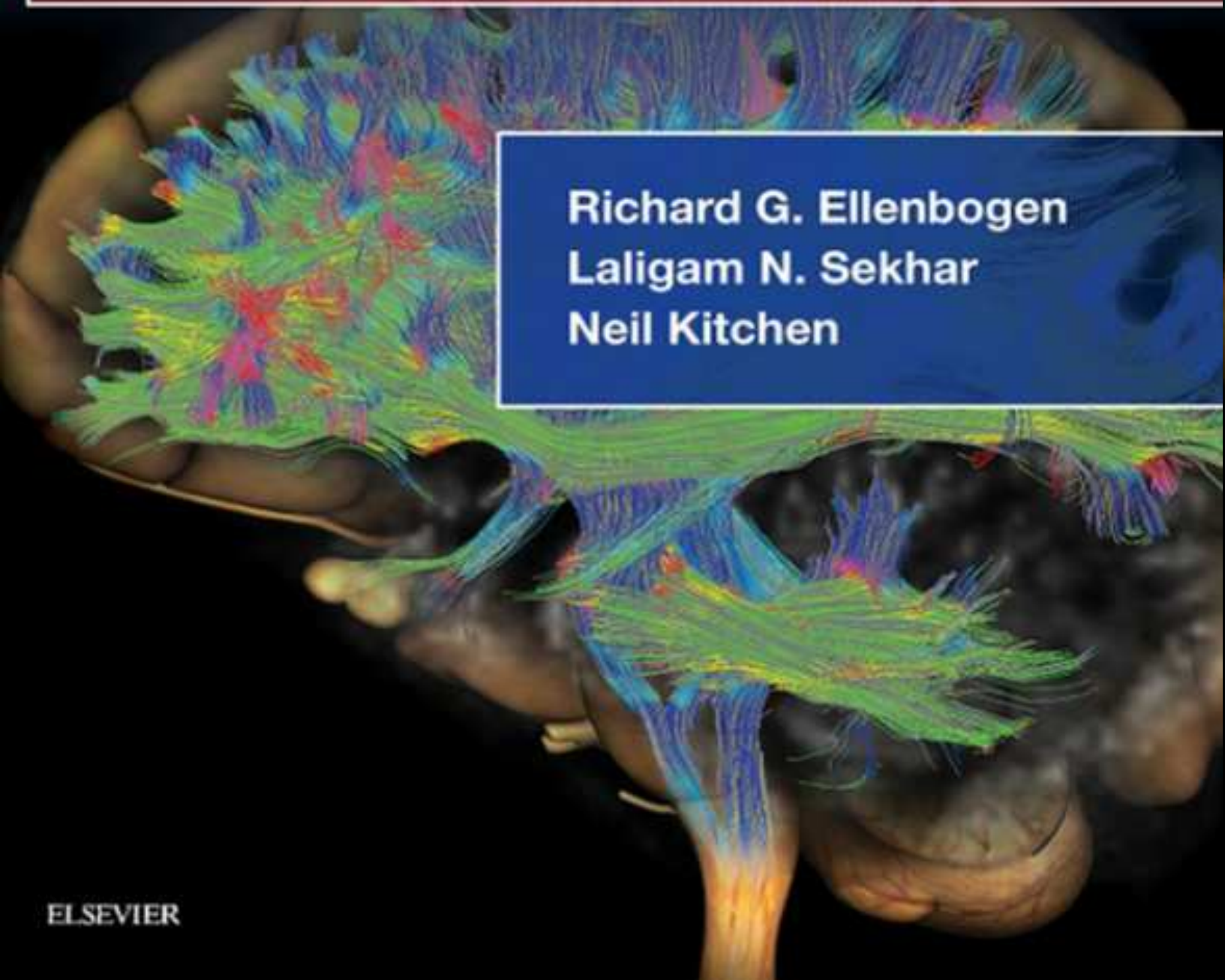
Principles of Neurological Surgery

FOURTH EDITION



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Fourth Edition

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To Sandy, Rachel, Paul, and Zach: Thank you for your patience, humor and love!

Rich Ellenbogen

I dedicate the book to my loving wife, Gordana; to my children, Daniela, Kris, and Raja, who constantly inspire me to greatness; and to my student Harley Brito da Silva, who toiled for countless hours helping to get this book finished.

Sekhar Laligam

To Mandy, Jim, Harry, and Molly

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Preface

Concern for man and his fate must always form the chief interest of all technical endeavors … Never forget this in the midst of your diagrams and equations.

ALBERT EINSTEIN

Principles of Neurological Surgery is in its fourth edition because of the popular demand of our students. We are thrilled to see the previous editions being read by medical students, house officers, nurses, and practicing neurosurgeons. It is for these treasured students, young and old, novice and experienced, that this book is intended. It is to be used to guide both those learning and those teaching. We are most indebted to our patients for inspiring us to perform at our best every day and pass on this experience to the next generation. We hope this edition contributes to the modest goal of shaping more informed clinicians, ultimately for the benefit and safety of our patients.

The world of medical education has evolved rapidly, and our students do not necessarily learn in the same manner we once learned. We have listened carefully to their constructive comments and presented a book that addresses their individual approach to learning basic neurological surgery principles. Scientific information is growing at an exponential rate. Thus, mastering the wide spectrum of neurological surgery is arguably even more challenging for the current generation of students than it was for our generation. A host of excellent encyclopedic neurological surgery reference texts currently are available. Our work is intended to be a simpler, coherent, practical education tool.

We hope it could be the sort of tool that students can use every day. We recognize that the internet and easily searchable peer-reviewed literature have often supplanted multivolume collections, so we took a different approach with this single volume text. It is our goal to make the complex and broad spectrum of neurological surgery more comprehensible. The text was then combined with the beautiful renderings of highly skilled artists, organized tables, and pertinent photographs to delineate both concepts and techniques. The authors added "Clinical Pearls" that sum up the critical bullet points of the chapters. The chapters are further supplemented with a section of "Selected Key References" from the bibliography, which the authors believe are worthy of in-depth investigation. Furthermore, we have listened to our students' desire for visual reinforcement and simulation to master psychomotor skills in the operating room. For that reason, we have included video clips for key operations. They can be downloaded from the Elsevier website and reviewed at any time from any location by those who desire to augment their understanding of the material.

I am fortunate to be joined by two exceptional neurological surgery talents: Professors Sekhar (USA) and Kitchen (Great Britain). These two professors possess a keen eye for the critical elements of our field. They are internationally recognized as master educators, as well as technical virtuosos. Of course, the success of this book truly rests upon a team of world class contributing scholars, known for their specific expertise, with this edition drawing from them new contributions. The entire project was then overseen by a patient and experienced Elsevier editing team.

I am deeply grateful to the authors, artists, and editors for the precious time and hard work invested in this third edition. They created a book with extraordinary visual appeal, containing accurate, evidence-based explanations, beautiful color illustrations, simple tables, illustrative photographs, and video highlights. It is our hope that this approach will be substantive, long lived, and enjoyable for our readers and beneficial to our patients.

Richard G. Ellenbogen

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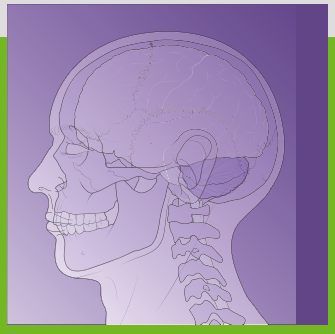


1 Landmarks in the History of Neurosurgery

JAMES TAIT GOODRICH

"If a physician makes a wound and cures a freeman, he shall receive ten pieces of silver, but only five if the patient is the son of a plebeian or two if he is a slave. However it is decreed that if a physician treats a patient with a metal knife for a severe wound and has caused the man to die—his hands shall be cut off."

—Code of Hammurabi (1792–50 BC)

In the history of neurosurgery there have occurred a number of events and landmarks, and these will be the focus of this chapter. In understanding the history of our profession, perhaps the neurosurgeon will be able explore more carefully the subsequent chapters in this volume to avoid having his or her "hands cut off."

To identify major trends and events in neurosurgery, this chapter has been organized into a series of rather arbitrary historical time periods. In each period the key themes, personalities, and neurosurgical techniques developed and used are discussed.

Prehistoric Period: the Development of Trephination

Neurosurgeons are often considered the second oldest profession, the first being prostitution. Early man (and woman) recognized that to take down a foe or an animal, a direct injury to the head was the quickest means. Having said that, prehistoric surgery, compared with its modern successor, lacked several essentials in its early development: an understanding of anatomy, recognition of the concept of disease, and comprehension of the origin of illness in an organic system. Failure to grasp these vital principles retarded the practice of both medicine and surgery. The "modern" art of surgery, and in particular that of neurosurgery, was not recognized as a discrete specialty until the early 20th century. Neurosurgeons have now advanced from mere "hole drillers" to sophisticated computer nerds running complex 21st-century stereotaxic frameless guided systems.

In many museum and academic collections around the world are examples of the earliest form of neurosurgery—skull trephination.[1–4] A number of arguments and interpretations have been advanced by scholars as to the origin and surgical reasons for this early operation—to date no satisfactory answers have been found. Issues of religion, treatment of head injuries, release of demons, and treatment of headaches have all been offered. Unfortunately, no adequate archaeological materials have surfaced to provide us with an answer. In reviewing some of the early skulls, the skills of these early surgeons were quite remarkable. Many of the trephined skulls show evidence of healing, proving that these early patients survived the surgery. Fig. 1.1 shows examples of two early (Peru circa AD 800) skulls that have been trephined and show evidence of premorbid bone healing. In the Americas the tumi was the most common surgical instrument used to perform a trephination, and some examples of these tumis are shown in Fig. 1.1. Fig. 1.2 presents a fine example of a well-healed gold inlay cranioplasty done by an early South American surgeon.

Included in many museum and private collections are examples of terra cotta and stone figures and other carvings that clearly depicted several common neurologic disorders. Commonly depicted by contemporary artisans were images of hydrocephalus, cranial deformation, spina bifida, and various forms of external injuries and scarring. We have added two examples from the Olmec and Mayan civilizations that demonstrate a young adult with achondroplasia and a young adult with severe kyphoscoliosis likely due to a myelomeningocele[5] (Fig. 1.3).

Egyptian and Babylonian Medicine: Embryonic Period

The Egyptian period, covering some 30 successive dynasties, gave us the earliest known practicing physician: Imhotep (I-em-herep) (3000 BC). Imhotep ("he whom cometh in

• **Figure 1.1** Two Peruvian skulls that date from about AD 600 showing a well-healed occipital trephination (*right skull*) and a well-healed frontal trephination (*left skull*). Three typical bronze/copper "tumis" used to make the trephination are illustrated between the skulls. (From the author's collection.)

• **Figure 1.2** An early cranioplasty done with a gold inlay, which is well healed. (From the Museum of Gold, Lima, Peru.)

peace") is considered the first medical demigod, one likely more skilled in magic and being a sage. From this period came three important medical and surgical documents that give us a contemporary view of the practice of surgery. These collections are the Ebers, Hearst, and Edwin Smith papyri, two of which are considered here.[6,7]

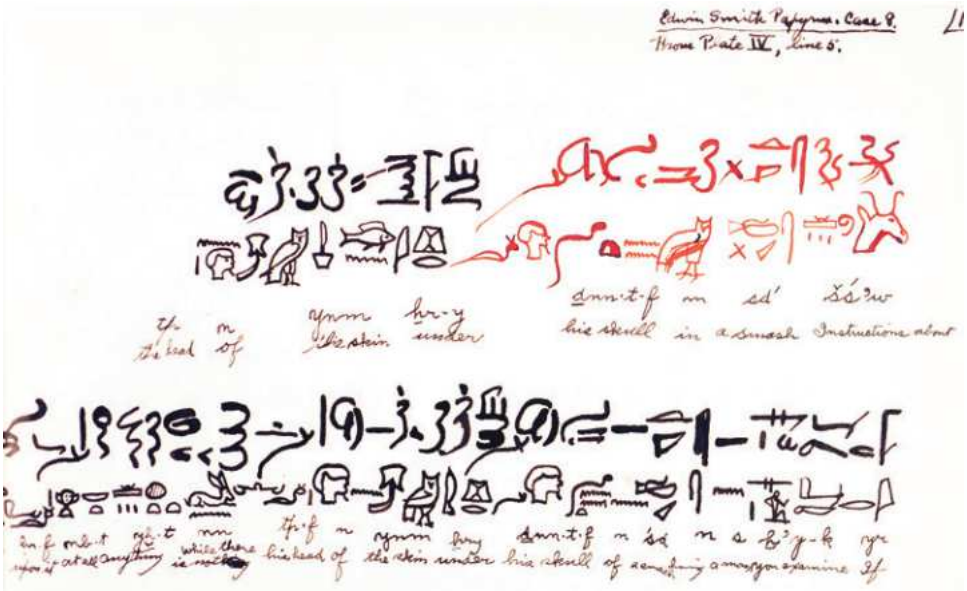
The Egyptians are well remembered for their skills developed in the practice of mummification. Historians have now shown that anatomic dissection was also performed in this period. An examination of the existing Egyptian papyri shows that the practice of medicine was based largely on magic and superstition. Therapeutic measures depended on simple principles, most of which allowed nature to provide restoration of health with little intervention. In treating skeletal injury, the Egyptians realized that immobilization was important and they prescribed splints for that purpose. Their materia medica was impressive, as their substantial pharmacopeias attest.

Written some 500 years after Hammurabi (1792–50 BC), and the oldest medical text believed to exist (including about 107 pages of hieratic writing), the Ebers papyrus is of interest for its discussion of contemporary surgical practice.[7] The text discusses the removal of tumors and recommends surgical drainage of abscesses.

The Edwin Smith papyrus, written after 1700 BC, is considered to be the oldest book on surgery per se and is a papyrus scroll 15 feet in length and 1 foot in width (4.5 m by 0.3 m; Fig. 1.4).[6] The text contains a total of 48 cases, including those with injuries involving the spine and cranium. Each case is considered with a diagnosis followed by a formulated prognosis. Owing to the scholarly work of James Breasted, this papyrus has been translated from the original Egyptian to English. The original document remains in the possession of the New York Academy of Medicine.[6]

Other than the isolated cases found in these papyrus fragments, little can be gleaned on the actual practice of neurosurgery. However, it is evident from these papyri that the Egyptian physician could classify a head and spine injury and would even elevate a skull fracture if necessary. The Edwin Smith papyrus (ca. 1700 BC) offers the first descriptions of the skull sutures, the presence of intracranial pulsations, and the presence of cerebrospinal fluid (CSF). The use of sutures in closing wounds and the applications of specifically designed head dressings for cranial injury appear here for the first time. The Egyptian physician's understanding of the consequences of a

• **Figure 1.3** (A) A Jadeite figure from the Olmec culture of Pre-Conquest Mexico dating from about 1500 BC showing a figure of an achondroplastic dwarf with likely arrested hydrocephalus. Individuals with some deformations such as achondroplasia were highly prized in the noble courts. (B) A west Mexico figure from the Pre-Conquest Nayarit area showing a severe kyphoscoliosis in a young adult with likely a primary problem of a myelomeningocele. (From the author's collection.)



• **Figure 1.4** A manuscript leaf from the Breasted translation of the Hearst papyrus discussing a head injury. (From Breasted JH. *The Edwin Smith Papyrus*. Published in Facsimile and Hieroglyphic Transliteration with Translation and Commentary. Chicago: University of Chicago Press; 1930; from the author's collection.)

cervical spine injury is clear from case 31, in which the injured individual is described with quadriplegia, urinary incontinence, priapism, and ejaculation in a cervical spine subluxation. The understanding of head and spine injury was further developed in the Greek schools of medicine; here we see the first treatment principles being offered on the management and codification of head injury.

Greek and Early Byzantine Period: the Origins of Neurosurgery

The first formal development of neurosurgery occurred with the golden age of Greece. During the ancient period there were no surgeons who restricted themselves *in stricto sensu* to "neurosurgery." Head injuries were plentiful then as the result of wars and internecine conflicts, as recorded by Herodotus and Thucydides as well as by Homer. The Greeks' love of gladiator sports also led to serious head injuries. So sports and war were then, as now, a principal source of material for the study and treatment of head injury.

The earliest medical writings from this period are those attributed to Hippocrates (460–370 BC), that most celebrated of the Asclepiadae, and his schools (Fig. 1.5).[8] To Hippocrates we owe the description of a number of neurologic conditions, many of them resulting from battlefield and sport injuries. Hippocrates was the first to develop the concept that the location of the injury to the skull was important in any surgical decision. The vulnerability of the brain to injury was categorized from lesser to greater by location, with injury to the bregma representing a greater risk than injury to the temporal region, which in turn was more dangerous than injury to the occipital region.[9]

• **Figure 1.5** One of the earliest known paintings of Hippocrates, Father of Medicine, dating from about the 8th century BC. (Courtesy of the Bibliothèque Nationale, Paris, France.)

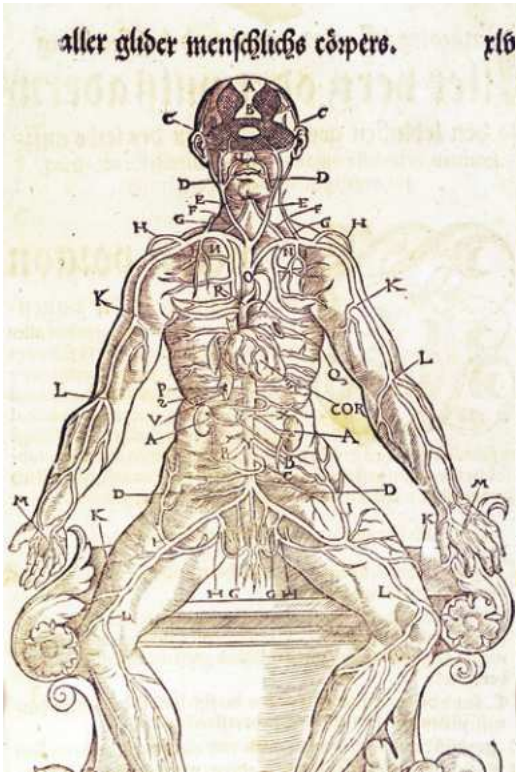
Hippocrates wrote on a number of neurologic conditions. From his *Aphorisms* is one of the earliest descriptions of subarachnoid hemorrhage: "When persons in good health are suddenly seized with pains in the head, and straightway are laid down speechless, and breathe with stertor, they die in seven days, unless fever comes on."[10]

Hippocrates provides the first written detailed use of the trephine. Insightful, he argued for trephination in brain contusions but not in depressed skull fractures (the prognosis was too grave) and cautioned that a trephination should never be performed over a skull suture because of the risk of injury to the underlying dura. Hippocrates demonstrated good surgical technique when he recommended "watering" the trephine bit while drilling to prevent overheating and injury to the dura.

Hippocrates had great respect for head injury. In the section on "Wounds of the Head," Hippocrates warned against incising the brain, as convulsions can occur on the opposite side. He also warned against making a skin incision over the temporal artery, as this could lead to contralateral convulsions (or perhaps severe hemorrhage from the skin). Hippocrates had a simple understanding of cerebral localization and appreciated serious prognosis in head injury.

Herophilus of Chalcedon (fl. 335–280 BC) was an important early neuroanatomist who came from the region of the Bosporus and later attended the schools of Alexandria. Unlike his predecessors, Herophilus dissected human bodies in addition to those of animals—more than 100 by his own account. Herophilus was among the first to develop an anatomic nomenclature and form a language of anatomy. Among his contributions was tracing the origin of nerves to the spinal cord. He then divided these nerves into motor and sensory tracts. He made the important differentiation of nerves from tendons, which were often confused at that time. In his anatomic writings are the first anatomic descriptions of the ventricles and venous sinuses of the brain. From him comes the description of confluens sinuum or *torcular Herophili.* The first description of the choroid plexus occurs here, so named for its resemblance to the vascular membrane of the fetus. Herophilus described in detail the fourth ventricle and noted the peculiar arrangement at its base, which he called the "calamus scriptorius" because it "resembles the groove of a pen for 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, in contrast to Aristotle's cardiocentric view.[11]

All was not perfect with this anatomist, as Herophilus is also remembered for introducing one of the longest standing errors in anatomic physiology: the rete mirabile (Fig. 1.6),[12] a structure present in artiodactyls but not in humans. This structure acts as an anastomotic network at the base of the brain. This inaccurately described structure later became dogma and important in early physiologic theories of human brain



• **Figure 1.6** Introduced in antiquity was the rete mirabile, an erroneous anatomic structure first discussed by Herophilus. This anatomic error was carried further in the writings of Galen and others and not corrected until the Renaissance. A nice example of this structure is illustrated here, from the Ryff 1541 book on anatomy. (From Ryff W. *Des Aller Furtefflichsten … Erschaffen. Das is des Menchen … Warhafftige Beschreibund oder Anatomi.* Strasbourg: Balthassar Beck; 1541.)

function. The rete mirabile was later erroneously described in detail by Galen of Pergamon and further canonized by later Arabic and medieval scholars. Scholarship did not erase this anatomic error until the 16th century, when the new anatomic accounts of Andreas Vesalius and Berengario da Carpi clearly showed it did not exist in humans.

Entering the Roman era and schools of medicine, we come to Aulus Cornelius Celsus (25 BC to AD 50). Celsus was neither a physician nor a surgeon; rather, he can best be described as a medical encyclopedist who had an important influence on surgery. His writings reviewed, fairly and with moderation, the rival medical schools of his time: dogmatic, methodic, and empiric. As counsel to the emperors Tiberius and Gaius (Caligula), he was held in great esteem. His book, *De re Medicina*,[13] is one of the earliest extant medical documents after the Hippocratic writings. His writings had an enormous influence on early physicians. So important were his writings that when printing was introduced in the 15th century, Celsus' works were printed before those of Hippocrates and Galen.

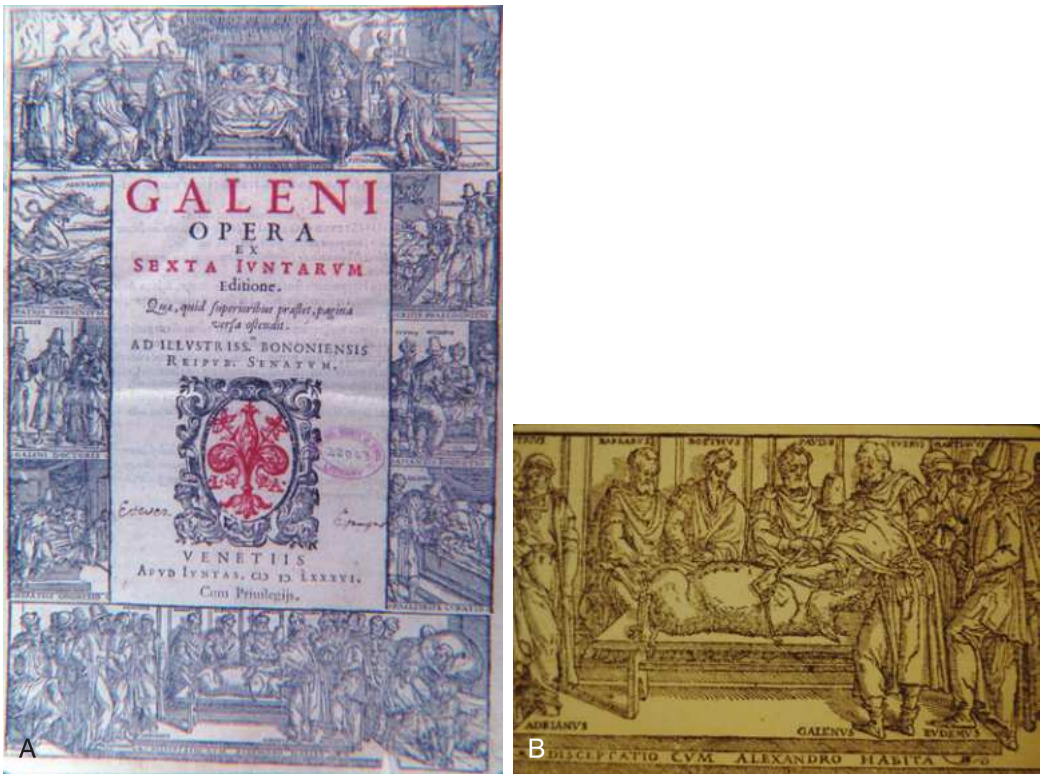
Celsus made a number of interesting neurosurgical observations. *De re Medicina* contains an accurate description of an epidural hematoma resulting from a bleeding middle meningeal artery.[8] Celsus comments that a surgeon should always operate on the side of greater pain and place the trephine where the pain is best localized. Considering the pain sensitivity of dura and its sensitivity to pressure, this has proved to be good clinical acumen. Celsus provided accurate descriptions of hydrocephalus and facial neuralgia. Celsus was aware that a fracture of the cervical spine can cause vomiting and difficulty in breathing, whereas injury of the lower spine can cause weakness or paralysis of the legs, as well as urinary retention or incontinence.

Rufus of Ephesus (fl. AD 100) lived during the reign of Trajan (AD 98–117) in the coastal city of Ephesus. Many of Rufus' manuscripts survived and became a heavy influence on the Byzantine and medieval compilers. As a result of his great skill as a surgeon, many of his surgical writings were still being transcribed well into the 16th century.[14] Rufus' description of the membranes covering the brain remains a classic. Rufus clearly distinguished between the cerebrum and cerebellum and gives a credible description of the corpus callosum. He had a good understanding of the anatomy of the ventricular system with clear details of the lateral ventricle; he also described the third and fourth ventricles, as well as the aqueduct of Sylvius. Rufus also provided early anatomic descriptions of the pineal gland and hypophysis, and his accounts of the fornix and the quadrigeminal plate are accurate and elegant. He was among the first to describe the optic chiasm and recognized that it was related to vision. The singular accuracy of Rufus' studies must be credited to his use of dissection (mostly monkeys) in an era when the Roman schools were avoiding hands-on anatomic dissection.

An individual of enormous influence was Galen of Pergamon (Claudius Galenus, AD 129–200). Galen was skilled as an original investigator, compiler, and codifier, as well as a leading advocate of the doctrines of Hippocrates and the Alexandrian school. As physician to the gladiators of Pergamon he had access to many human traumatic injuries.

His experience as a physician and his scientific studies enabled Galen to make a variety of contributions to neuroanatomy. Galen was the first to differentiate the pia mater and the dura mater. Among his contributions were descriptions of the corpus callosum, the ventricular system, the pineal and pituitary glands, and the infundibulum. Long before Alexander Monro's *Secundus* (1733–1817) 18th-century anatomic description, Galen clearly described the structure now called the *foramen of Monro.* He also gave an accurate description of the aqueduct of Sylvius. He performed a number of interesting anatomic experiments, such as transection of the spinal cord, leading him to describe the resultant loss of function below the level of the cut. In a classic study on the pig, he sectioned the recurrent laryngeal nerve and clearly described that hoarseness was a consequence (Fig. 1.7). Galen provides the first recorded attempt at identifying and numbering the cranial nerves. He described 11 of the 12 nerves, but by combining several, he arrived at a total of only 7. He regarded the olfactory nerve as merely a prolongation of the brain and hence did not count it.[15]

In viewing brain function Galen offered some original concepts. He believed the brain controlled intelligence, fantasy,



• **Figure 1.7** (A) Title page from Galen's *Opera Omnia*, Juntine edition, Venice. The border contains a number of allegoric scenes showing the early practice of medicine. (B) The bottom middle panel is shown here enlarged in which Galen is performing his classic study on the section of the recurrent laryngeal nerve and resulting hoarseness in the pig. (From Galen. *Omnia Quae Extant Opera in Latinum Sermonem Conversa,* 5th ed. Venice: Juntas; 1576–1577.)

memory, and judgment. This was an important departure from the teaching of earlier schools, for example, Aristotle's cardiocentric view. Galen discarded Hippocrates' notion that the brain is only a gland and attributed to it the powers of voluntary action and sensation.

With animal experimentation Galen recognized that cervical injury can cause disturbance in arm function. In a study of spinal cord injury, Galen detailed a classic case of what is today known as *Brown-Séquard syndrome* (ie, a hemiplegia with contralateral sensory loss in a subject with a hemisection of the cord).[16] Galen's description of the symptoms and signs of hydrocephalus is classic. This understanding of the disease enabled him to predict which patients with hydrocephalus had a poorer prognosis. Galen was much more liberal in the treatment of head injury than Hippocrates, arguing for more aggressive elevation of depressed skull fractures, fractures with hematomas, and comminuted fractures. Galen recommended removing the bone fragments, particularly those pressing into the brain. Galen was also more optimistic than Hippocrates about the outcome of brain injuries, commenting that "we have seen a severely wounded brain healed."

Paul of Aegina (AD 625–690), trained in the Alexandrian school, is considered the last of the great Byzantine physicians. He was a popular writer who compiled works from both the Latin and Greek schools. His writings remained extremely popular, being consulted well into the 17th century. Besides his medical skills Paul was also a skilled surgeon to whom patients came from far and wide. He venerated the teachings of the ancients as tradition required but also introduced his own techniques with good results. This author is best remembered for his classic work, *The Seven Books of Paul of Aegina*, within which are excellent sections on head injury and the use of the trephine.[17,18] Paul classified skull fractures in several categories: fissure, incision, expression, depression, arched fracture, and, in infants, dent. In skull fractures he developed an interesting skin incision which involved two incisions intersecting one another at right angles, giving the Greek letter X. One leg of the incision incorporated the scalp wound. To provide comfort for the patient, the ear was stuffed with wool so that the noise of the trephine would not cause undue distress. In offering better wound care he dressed it with a broad bandage soaked in oil of roses and wine, with care taken to avoid compressing the brain.[18]

Paul of Aegina had some interesting views on hydrocephalus, which he felt was sometimes a result of a man-handling midwife. He was the first to suggest the possibility that an intraventricular hemorrhage might 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 … (Paulus Aeginetes).[18]

An innovative personality, he designed a number of surgical instruments for neurosurgical procedures. Illustrated in his early manuscripts are a number of tools including elevators, raspatories, and bone-biters. An innovation for his trephine bits was a conical design to prevent plunging, and different biting edges were made for ease of cutting. Reviewing his wound management reveals some sophisticated insights—he used wine (helpful in antisepsis, although this concept was then unknown) and stressed that dressings should be applied with no compression to the brain. Paul of Aegina was later to have an enormous influence on Arabic medicine and in particular on Albucasis, the patriarch of Arabic/Islamic surgery.[19]

Arabic and Medieval Medicine: Scholarship With Intellectual Somnolence

From approximately AD 750 to AD 1200 the major intellectual centers of medicine were with the Arabic/Islamic and Byzantine cultures. As Western Europe revived after AD 1000, a renewed study of surgery and medicine developed there as well.

Arabic/Islamic Scholarship

As we move out of the Byzantine period the Arabic/Islamic schools became paramount in the development of medicine and surgery. Thriving Arabic/Islamic schools undertook an enormous effort to translate and systematize the surviving Greek and Roman medical texts. Thanks to their incredible zeal, the best of Greek and Roman medicine was made available to Arabic readers by the end of the 9th century, an enormous contribution. Although a rigid scholastic dogmatism became the educational trend, original concepts and surgical techniques were clearly introduced during this period. In anatomic studies some of the more prominent figures actually challenged Galen and some of his clear anatomic errors.

Islamic medicine flourished from the 10th century through the 12th century. Among the most illustrious scholars/writers/physicians were Avicenna, Rhazes, Avenzoar, Albucasis, and Averroes. In the interpretative writings of these great physicians one sees an extraordinary effort to canonize the writings of their Greek and Roman predecessors. Islamic scholars and physicians served as guardians and academics of what now became Hippocratic and Galenic dogma. But having said this, there is clear evidence that these scholars and physicians continued original research and performed anatomic studies, a procedure not forbidden in either the Koran or Shareeh, a common Western view.

In reviewing this period, one finds that physicians rarely performed surgery. Rather, it was expected that the physician would write learnedly and speak *ex cathedra* from earlier but more "scholarly" writings. The menial task of surgery was assigned to an individual of a lower class—that is, to a surgeon. Despite this trend several powerful and innovative personalities did arise, and we will review their contributions.

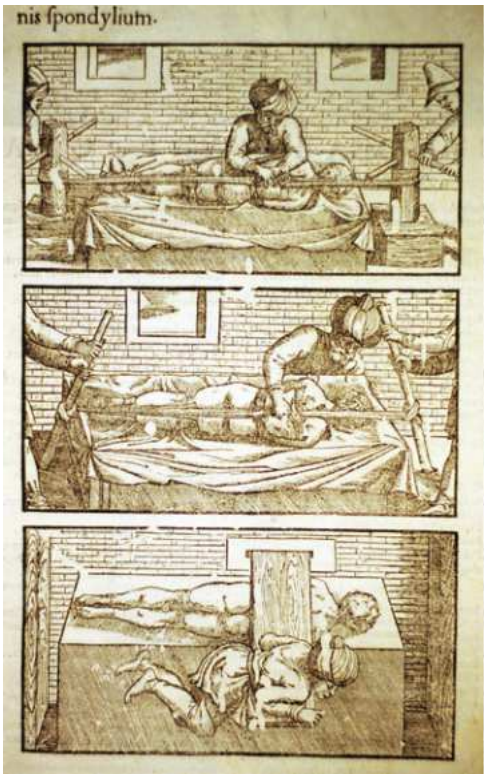
In this era of Islamic medicine we see introduced a now common medical tradition—bedside medicine with didactic teaching. Surgeons, with rare exceptions, remained in a class of low stature. One unfortunate practice was the reintroduction of the Egyptian technique of using a red-hot cautery iron, applied to a wound, to control bleeding. In some cases hot cautery was used instead of the scalpel to create surgical incisions, and this practice clearly led to a burned and subsequent poorly healed wound (Fig. 1.8).

An important Islamic scholar of this period, as reflected in his writings, was Rhazes (Abu Bakr Muhammad ibn Zakariya' al-Razi, AD 845–925). Reviewing his works one sees clearly a scholarly physician, loyal to Hippocratic teachings, and learned in diagnosis. Although primarily a court physician and not a surgeon, he provided writings on surgical topics that remained influential through the 18th century.[20] Rhazes was one of the first to discuss and outline the concept of cerebral concussion. Head injury, he wrote, is among the most devastating of all

• **Figure 1.8** (A) Ottoman empire physician applying cautery to the back. (B) Manuscript leaf showing Avicenna reducing and stabilizing a spinal column injury. (From Sabuncuoglu S. Cerrahiyyetü'l-Haniyye [Imperial Surgery] [translated from Arabic]. Ottoman Empire circa 15th century. From a later copied manuscript in the author's collection, circa 1725.)

injuries. Reflecting some insight, he advocated surgery only for penetrating injuries of the skull as the outcome was almost always fatal. Rhazes recognized that a skull fracture causes compression of the brain and thereby requires elevation to prevent lasting injury. Rhazes also understood that cranial and peripheral nerves have both a motor and sensory component. In designing a surgical scalp flap one needed to know the anatomy and pathways of the nerves so as to prevent a facial or ocular palsy.

Avicenna (Abu 'Ali al-Husayn ibn 'Abdallah ibn Sina, AD 980–1037), the famous Persian physician and philosopher of Baghdad, was known as the "second doctor" (the first being Aristotle). During the Middle Ages his works were translated into Latin and became dominant teachings in the major European universities until well into the 18th century. With the introduction of the printed book it has been commented that his *Canon (Q'anun)* was the second most commonly printed book after the Bible. Avicenna disseminated the Greek teachings so persuasively that their influence remains an undercurrent to this day. In his major work, *Canon Medicinae (Q'anun)*, an encyclopedic effort founded on the writings of Galen and Hippocrates, the observations reported are mostly clinical, bearing primarily on materia medica (Fig. 1.9).[21] Avicenna's medical philosophy primarily followed the humoral theories of Hippocrates along with the biologic concepts of Aristotle. Within Avicenna's *Canon (Q'anun)* are a number of interesting neurologic findings, such as the first accurate clinical explanation of epilepsy, for which treatment consisted of various medications and herbals along with the shock of the electric eel. He describes meningitis and recognized it was an infection and inflammation of the meninges. It appears that Avicenna might have conducted anatomic studies inasmuch as he gives a correct anatomic discussion of the vermis of the cerebellum and the "tailed nucleus," now known as the *caudate nucleus.* Avicenna introduced the concept of a tracheostomy using a gold or silver tube placed into the trachea and provided a number of innovative techniques for treating spine injuries and included some devices for stabilizing the injured spine. Avicenna also had some insightful thoughts on the treatment of hydrocephalus. He recognized that external hydrocephalus (fluid between the brain and dura) could be drained with low morbidity risk. However, true internal hydrocephalus was more dangerous to treat and best left alone or treated with herbals and medications.[22] The *Canon (Q'anun)* was clearly his greatest contribution, along with his collation and translation of Galen's collected works, a book that remained a dominant influence until well into the 18th century.



• **Figure 1.9** Avicenna developed a number of devices to deal with spinal injury and spinal stabilization. Illustrated here is a "rack" system using a series of winches and stretching devices to realign the spine. (From Avicenna. *Liber Canonis, de Medicinis Cordialibus, et Cantica.* Basel: Joannes Heruagios; 1556.)

A personality often overlooked in neurosurgical history was a prominent Persian/Islamic physician by the name of Haly Abbas (Abdul-Hasan Ali Ibn Abbas Al Majusi) (?AD 930–44). This writer from the Golden Age of Islamic medicine produced a work called *The Perfect Book of the Art of Medicine*,[23] also known as the *Royal Book* (Fig. 1.10). Born and educated in Persia, a place he never left, it was here he produced his important writings on medicine. In his book he dedicated 110 chapters to surgical practice. A review of his work shows that his writings on spine injuries were essentially copied from the earlier Greek writers, in particular Paul of Aegina, and consisted mostly of external stabilization of spinal column injuries. Surgical intervention via a scalpel was rarely advocated. In his nineteenth discourse, Chapters 84 and 85, his management of depressed skull fractures is clearly presented. He also described the different types of fractures that can occur along with potential mechanisms of injury. He clearly appreciated that the dura should be left intact and not violated, the exception being those fractures where the skull bone had penetrated through the dural membrane, in which case these fragments needed to be removed. His technique of elevating a bone flap involved drilling a series of closely placed holes and then connecting them with a chisel. He showed some interesting consideration for the patient by advocating placing a ball of wool into the ears so as to block the sounds from the drilling. The head wound was then dressed with a wine-soaked dressing, the wine likely providing a form of antisepsis. These chapters also contain an interesting discussion about intraoperative brain swelling and edema, in which case the surgeon should look further for possible retained bone fragments and remove them. If later swelling occurred from too tight a head dressing, then it should be loosened. Unfortunately, Haly Abbas also advocated cephalic vein bleeding and inducing diarrhea for those who did not respond well; such primitive techniques were not to be abandoned until the mid-19th century.

In the Islamic tradition Albucasis (Abu al-Qasim Khalaf ibn al-Abbas Al-Zahrawi, AD 936–1013) was both a great

• **Figure 1.10** Title page from the second printed edition of Haly Abbas' writings on medicine and surgery. In this allegorical title page we see Haly Abbas in the center and Galen and Hippocrates to each side. (From Haly Abbas [Abdul-Hasan Ali Ibn Abbas Al Majusi]. *Liber Totius Medicine necessaria continens quem sapientissimus Haly filius Abbas discipulus Abimeher Muysi filii Sejar editit: regique inscripsit unde et regalis depositionis nomen assumpsit. Et a Stephano philosophie discipulo ex Arabica lingua in Latinam … reductus. Necnon a domino Michaele de Capella … Lugduni.* Lyons: Jacobi Myt; 1523.)

• **Figure 1.11** Illustrated here are some of Albucasis' instrument designs including a couple of cephalotomes for dealing with hydrocephalus in the infant. (From Albucasis. *Liber Theoricae Necnon Practicae Alsaharavii.* Augsburg: Sigismundus Grimm & Marcus Vuirsung; 1519.)

compiler as well as a serious scholar, whose writings (some 30 volumes!) focused mainly on surgery, dietetics, and materia medica. In the introduction to his *Compendium*[24] there is an interesting discussion of why the Islamic physician had made such little progress in surgery—he attributed this failure to a lack of anatomic study and inadequate knowledge of the classics. One unfortunate medical practice that he popularized was the frequent use of emetics as prophylaxis against disease, a debilitating medical practice that survived, as "purging," into the 19th century.

The final section of the *Compendium* is the most important part for surgeons and includes a lengthy summary of surgical practice at that time.[24–26] This work was used extensively in the schools of Salerno and Montpellier and hence was an important influence in medieval Europe. A unique feature of this text was the illustrations of surgical instruments along with descriptions of their use, which Albucasis detailed in the text. Albucasis designed many of the instruments, and some were based on those described earlier by Paul of Aegina. His design of a "nonsinking" trephine is classic (he placed a collar on the trephine to prevent plunging) and was to become the template of many later trepan/trephine designs (Fig. 1.11).

Albucasis' treatise on surgery is an extraordinary work—a rational, comprehensive, and well-illustrated text designed to teach the surgeon the details of each treatment, including the types of wound dressings to be used. Yet one can only wonder how patients tolerated some of the surgical techniques. For chronic headache a hot cautery was applied to the occiput, burning through the skin but not the bone. Another headache treatment required hooking the temporal artery, twisting it, placing ligatures, and then in essence ripping it out! Albucasis recognized the implications of spinal column injury, particularly dislocation of the vertebrae: in total subluxation, with the patient showing involuntary activity (passing urine and stool) and flaccid limbs, he appreciated that death was almost certain. Some of the methods he advocated for reduction of lesser spinal injuries, using a combination of spars and winches, were rather dangerous. With good insight he argued that bone fragments in the spinal canal should be removed. To provide comfort for the patient undergoing surgery he developed an "anesthesia" sponge in which active ingredients included opium and hashish; the sponge would be applied to the lips of the patient until the patient became unconscious.

For hydrocephalus (following the teachings of Paul of Aegina, he associated the disorder with the midwife grasping the head too roughly) Albucasis recommended drainage, although he noted that the outcome was almost always fatal. He attributed these poor results to "paralysis" of the brain from relaxation. With regard to the site for drainage, Albucasis noted

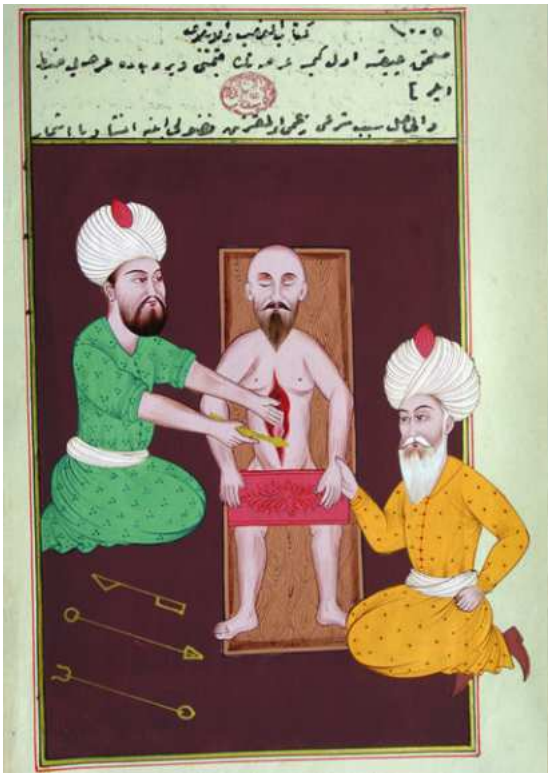
that the surgeon must never cut over an artery, as hemorrhage could lead to death. In the child with hydrocephalus he would "bind" the head with a tight constricting head wrap and then put the child on a "dry diet" with little fluid—in retrospect a progressive treatment plan for hydrocephalus.[25,26]

An important figure in the history of surgery, and one who bridged the Islamic and medieval schools, was Serefeddin Sabuncuoglu (1385–1468). Sabuncuoglu was a prominent Ottoman surgeon who lived in Amasya, a small city in the northern region of Asia Minor, part of present-day Turkey. This was a glorious period for the Ottoman Empire and Amasya was a major center of commerce, culture, and art. While working as a physician at Amasya Hospital, and at the age of 83, he wrote a medical book titled *Cerrahiyyetü'l-Haniyye [Imperial Surgery]*, which is considered the first colored illustrated textbook of Turkish medical literature.[27–30] There are only three known copies of this original manuscript, two are in Istanbul and the third at the Bibliothèque Nationale in Paris.[27] First written in 1465 the book consists of three chapters covering 191 topics, all dealing with surgery. Each topic consists of a single, poetical sentence in which the diagnosis, classification, and surgical technique of a particular disease are described in detail. This book is unique for this period in that virtually all the surgical procedures and illustrations were drawn in color, even though drawings of this type were prohibited in the Islamic religion (Fig. 1.12).

Medieval Europe

Constantinus Africanus (Constantine the African) (1020–87) introduced Islamic medicine to the school of Salerno and thus to Europe (Fig. 1.13). Constantine had studied in Baghdad, where he came under the influence of the Islamic/Arabic scholars. Later, he retired to the monastery at Monte Cassino and there translated Arabic manuscripts into Latin, some scholars say rather inaccurately. Thus began a new wave of translation and transliteration of medical texts, this time from Arabic back into Latin.[31] His work allows one to gauge how much medical and surgical knowledge was lost or distorted by multiple translations, particularly of anatomic works. It is also notable that Constantine reintroduced anatomic dissection with an annual dissection of a pig. Unfortunately the anatomic observations that did not match those recorded in the early classical writings were ignored! As had been the theme for the previous 400 years, surgical education and practice continued to slumber.

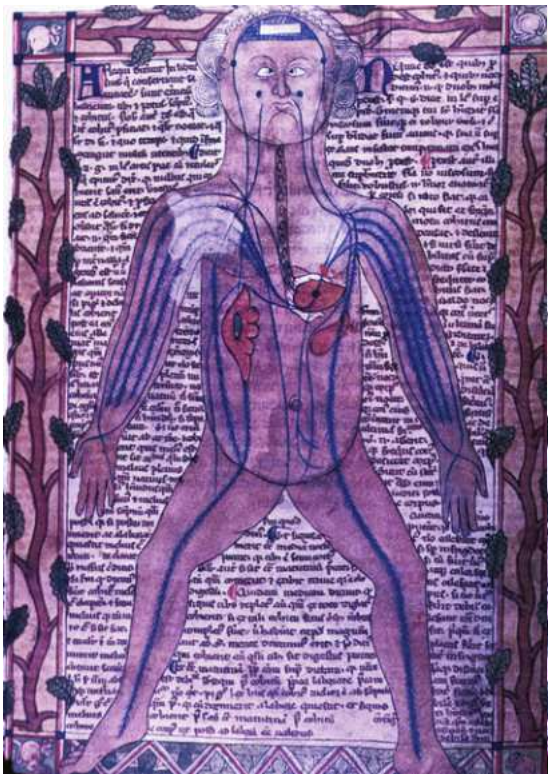
Roger of Salerno (fl. 1170) was a surgical leader in the Salernitan tradition, the first writer on surgery in Italy. His work on surgery was to have a tremendous influence during the medieval period (Fig. 1.14). His *Practica Chirurgiae* offered some interesting surgical techniques.[32] Roger introduced an unusual technique of checking for a tear of the dura (ie, cerebrospinal fluid [CSF] leakage) in a patient with a skull fracture by having the patient hold his breath (Valsalva maneuver) and



• **Figure 1.12** An unusual colored illustration of an anatomic dissection being done by Arabic/Islamic physicians. Often thought to have been forbidden by the Koran, anatomic dissections were done in the Byzantine and Medieval periods by this group of physicians and anatomists. (From the author's personal collection.)

• **Figure 1.13** Constantine the African lecturing at the great School of Salerno. In the typical fashion of the day, the professor is giving an "ex cathedra" lecture to the students on medicine reading from the codices of Hippocrates and Galen. (A 17th-century leaf from the author's collection.)

• **Figure 1.14** This early medieval manuscript illustrates a craniotomy being performed by Roger of Salerno. (From Bodleian Library, Oxford, UK.)



• **Figure 1.15** From the "five-figure series," this illustration reveals the Middle Ages understanding of the circulatory and nervous systems of man with the Galenic anatomic error of the rete mirabile clearly illustrated. (From Bodleian Library Collection, Oxford, England.)

then watching for a CSF leak or air bubbles. A pioneer in the techniques of managing nerve injury, he argued for reanastomosis of severed nerves. During the repair he paid particular attention to alignment of the nerve fascicles. Several chapters of his text are devoted to the treatment of skull fractures, as described in the following discussion.

> 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 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.[32]

In reviewing the writings of Roger of Salerno we see little offered that is new in the field of anatomy. He contented himself with recapitulating earlier treatises, in particular those of Albucasis and Paul of Aegina. He strongly favored therapeutic plasters and salves; fortunately he was not a strong advocate of the application of grease to dural injuries. Citing the writings of *The Bamberg Surgery*,[33] he advocated trephination in the treatment of epilepsy.

An unusually inventive medieval surgeon, Theodoric Borgognoni of Cervia (1205–98) is remembered as 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." He made a number of attempts to discover the ideal conditions for good wound healing; he concluded that they comprised control of bleeding, removal of contaminated or necrotic material, avoidance of dead space, and careful application of a wound dressing bathed in wine—views that are remarkably modern for the times (Fig. 1.15).

Theodoric's surgical work, written in 1267, provides a unique view of medieval surgery.[34] He argued for meticulous (almost Halstedian!) surgical techniques. The aspiring surgeon was to train under competent surgeons and be well read in the field of head injury. Interestingly, he argued that parts of the brain could be removed through a wound with little effect on the patient. He appreciated the importance of skull fractures, especially depressed ones, recognizing that they should be elevated. He believed that punctures or tears of the dura mater could lead to abscess formation and seizures. To provide comfort for the patient about to undergo surgery, he developed his own "soporific sponge," which contained opium, mandragora, hemlock, and other ingredients. It was applied to the nostrils until the patient fell asleep. He describes results in improved comfort that were better for both patient and surgeon (Figs. 1.16 and 1.17).

• **Figure 1.16** A medieval image of the "typical" lecture of the period with the professor speaking "ex cathedra" to the student reading from classic texts from Hippocrates, Galen, and other classical writers. (Attributed to Gerard of Cromona, a translator of Avicenna Canon Medicinae, Paris circa 1320. Bibliotheca Nationale, Paris, France.)

• **Figure 1.17** Medieval anatomist performing a dissection of the head. (From Guido de Papia [Papaya], Anatomia circa 1325. Musèe Condé, Chantilly, France.)

William of Saliceto (1210–77) might be considered the ablest surgeon of the 13th century. A professor at the University of Bologna, William of Saliceto wrote his *Chirurgia*,[35] which many consider to be highly original, though it does carry the strong influence of Galen and Avicenna. To his credit William replaced the Arabic technique of incision by cautery with the surgical knife. He also devised techniques for nerve suture. In neurology, he recognized that the cerebrum governs voluntary motion and the cerebellum involuntary function.

Leonard of Bertapalia (1380?–1460) was a prominent figure in medieval surgery. Leonard came from a small town near Padua and established an extensive and lucrative practice there and in nearby Venice. He was among the earliest proponents of anatomic research—in fact, he gave a course of surgery in 1429 that included the dissection of an executed criminal. Leonard had a strong interest in head injury—he ended up devoting a third of his book to surgery of the nervous system.[36,37] He considered the brain the most precious organ, regarding it as the source of voluntary and involuntary functions. He provided some interesting and accurate insights into the management of skull fracture. He argued that the surgeon should always avoid materials that might cause pus, always avoid the use a compressive dressing that might drive bone into the brain, and if a piece of bone pierces the brain, remove it!

Lanfranchi of Milan (c. 1250–1306), a pupil of William of Saliceto, continued his teacher's practice of using a knife instead of cautery. In his *Cyrurgia Parva* he pioneered the use of suture for wound repair.[38] His guidelines for performing trephination in skull fractures and "release of irritation" of dura are classic. He even developed a technique of esophageal intubation for surgery, a technique not commonly practiced until the late 19th century.

Guy de Chauliac (1298–1368) was the most influential surgeon of the 14th and 15th centuries and a writer of rare learning and fine historical sense. So important to surgical practice did Guy de Chauliac's *Ars Chirurgica* become, it was copied and translated into the 17th century, a span of nearly 400 years. Most historians consider this surgical manual to be the principal didactic surgical text of this era.[39,40]

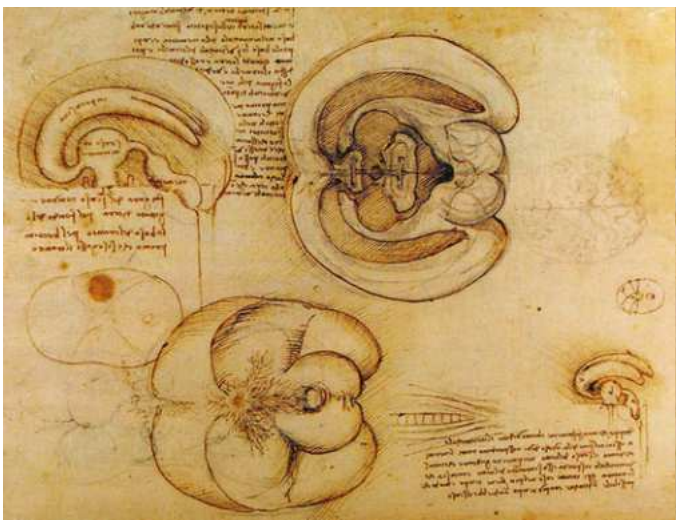
The discussion of head injuries in his *Ars Chirurgica* reveals the breadth of his knowledge and intellect. He recommended that prior to doing cranial surgery the head should be shaved to prevent hair from getting into the wound and interfering with primary healing. When dealing with depressed skull fractures he advocated putting wine into the depression to assist healing—an interesting early form of antisepsis. He categorized head wounds into seven types and described the management of each in detail. Surgical management of a scalp wound requires only cleaning and débridement, whereas a compound depressed skull fracture must be treated by trephination and bone elevation. For wound repairs he advocated a primary suture closure and described good results. For hemostasis he introduced the use of egg albumin, thereby helping the surgeon to deal with a common and difficult problem.

Sixteenth Century: Anatomic Exploration

With the beginnings of the Renaissance, profound changes began to occur in surgical practices. To resolve medical and surgical practice issues, both physicians and surgeons reintroduced basic hands-on investigative techniques. Of profound influence was the now routine practice of anatomic dissection of humans. A series of prominent figures including Leonardo da Vinci, Berengario da Carpi, Johannes Dryander, Andreas Vesalius, and others led the movement. Anatomic errors, many ensconced since the Greco-Roman era, were corrected, and a greater interest in surgery developed. This radically inventive period and its personalities laid the foundations of modern neuroanatomy and neurosurgery.

Leonardo da Vinci (1452–1519) was the quintessential Renaissance man. Multitalented, recognized as an artist, an anatomist, and a scientist, Leonardo went to the dissection table so as to better understand surface anatomy and its bearing on his artistic creations. On the basis of these studies he founded iconographic and physiologic anatomy.[41–43] Leonardo, being a well-read man, was familiar with the writings of Galen, Avicenna, Mondino, and others. From his knowledge of these writings he developed an understanding of their anatomic errors.

To Leonardo's studies we owe a number of anatomic firsts. Leonardo provided the first crude diagrams of the cranial nerves, the optic chiasm, and the brachial and lumbar plexuses. Leonardo made the first wax casting of the ventricular system and in so doing provided the earliest accurate view of this anatomy. His wax casting technique involved removing the brain from the calvarium and injecting melted wax through the fourth ventricle. Tubes were placed in the lateral ventricles to allow air to escape. When the wax hardened he removed the brain, leaving a cast behind—simple but elegant (Fig. 1.18).



• **Figure 1.18** From Leonardo's anatomic codices: using a wax casting design of his own, Leonardo was able to outline the ventricular system. The technique involved filling the ventricles with a warm wax and an egress tube to allow the air out. (From Leonardo da Vinci. *Quaderni d'Anatomia.* Christiania: Jacob Dybwad; 1911–1916.)

In connection with his art studies he developed the concept of *antagonism* in muscle control. His experimental studies included sectioning a digital nerve and noting that the affected finger no longer had sensation, even when placed in a fire. Leonardo had great plans for publishing a stupendous opus on anatomy, which was to be issued in 20 volumes. The work did not appear owing to the early death of his collaborator, Marcantonio della Torre, who died in 1509.[44] From 1519, the year of Leonardo's death, until the middle of the 16th century, his anatomic manuscripts circulated among Italian artists through the guidance of Francesco da Melzi, Leonardo's associate. Sometime in the mid- to late 16th century, the anatomic manuscripts were lost and were rediscovered only in the 18th century by William Hunter.

Ambroise Paré (1510–90), a poorly educated and humble Huguenot, remains one of the greatest figures in surgical history; indeed, many considered him to be the father of modern surgery. Using the surgical material from a long military experience, he was able to incorporate a great deal of practical knowledge into his writings. Paré did an unusual thing in that he published his books in the vernacular, in this case French rather than Latin. His use of French, rather than Latin, allowed a wider dissemination of his writings. Owing to his surgical prowess and good results, Paré became a popular surgeon with royalty. The fatal injury sustained by Henri II of France was an important case, from which some insight into Paré's understanding of head injury can be obtained. Paré attended Henri II at the time of the injury and was also present at the autopsy. Paré's clinical observations of this case included headache, blurred vision, vomiting, lethargy, and decreased respiration. At autopsy the king was found to have developed a subdural hematoma. Using the clinical observations and the history, Paré postulated that the injury was due to a tear in one of the bridging cortical veins, and the autopsy confirmed his observations.

In reviewing Paré's surgical works,[45,46] the part on the brain best reflects a contemporary surgical practice. Book X is devoted to skull fractures. Paré reintroduced the earlier technique of elevating a depressed skull fracture by using 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."[36] This maneuver also assisted in the expulsion of blood and pus (Fig. 1.19).

In reviewing Paré's surgical techniques we find a remarkable advance over previous writers. Paré provides extensive discussions on the use of trephines, shavers, and scrapers. He advocates removing any osteomyelitic bone, incising the dura, and evacuating blood clots and pus—procedures previously carried out with great trepidation by less well-trained surgeons. Paré strongly advocated wound débridement, emphasizing that all foreign bodies must be removed. An important advance in surgery by Paré was the serendipitous discovery that boiling oil should not be poured into wounds, particularly gunshot wounds. While in battle he ran out of the boiling oil and instead he made a dressing of egg yolk, rose oil, and turpentine. With this new formulation he found greatly improved wound

• **Figure 1.19** (A) Title page from the English translation of Ambroise Paré's great surgical treatise. Paré is illustrated in the top middle panel, and a trephination scene is in the top left panel, which is enlarged in the next figure. (B) Trephination scene from the title of Paré's work enlarged. As a military surgeon, Paré performed numerous treatments of head injuries and skull fractures. (From Paré A. [Johnson T, translator]. *The Workes of That Famous Chirurgion Ambroise Parey.* London: Richard Coates; 1649.)

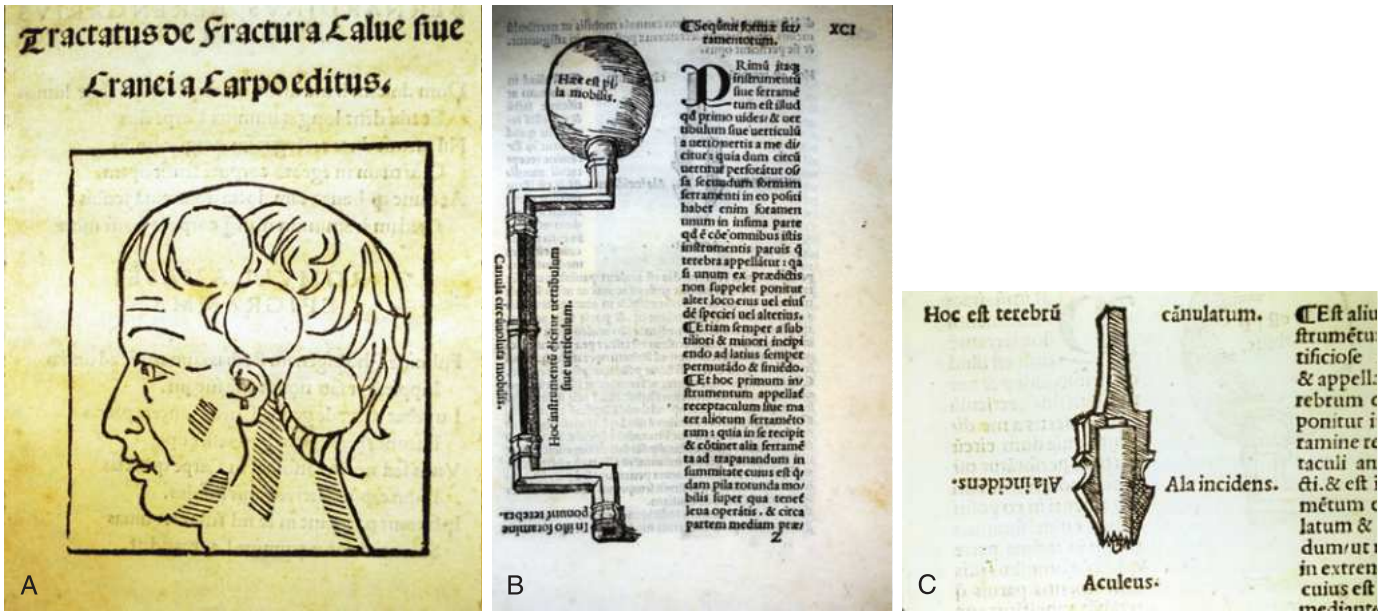
healing and dramatically reduced morbidity and mortality. He also discarded the use of hot cautery to control bleeding, substituting the use of ligatures, which enhanced healing and significantly reduced blood loss, particularly in amputations.

In 1518 a remarkable book by Giacomo Berengario da Carpi (1460–1530) appeared.[47] This book came about because of Berengario's success in treating Lorenzo de' Medici, Duke of Urbino, who had received a serious cranial injury and survived. In a dream that occurred shortly after this episode, Berengario was visited by the god Hermes Trismegistus (Thrice-Great Mercury), who encouraged him to a write a treatise on head injuries. As a result of this dream Berengario's *Tractatus* appeared and was the first printed work devoted solely to treating injuries of the head. Not only are original surgical techniques discussed, but also illustrations of the cranial instruments for dealing with skull fractures are provided (Fig. 1.20). Berengario introduced the use of interchangeable cranial drill bits for trephination. Included in the text are a number of case histories with descriptions of the patients, methods of treatment, and clinical outcomes. This work remains our best 16th-century account of brain surgery.

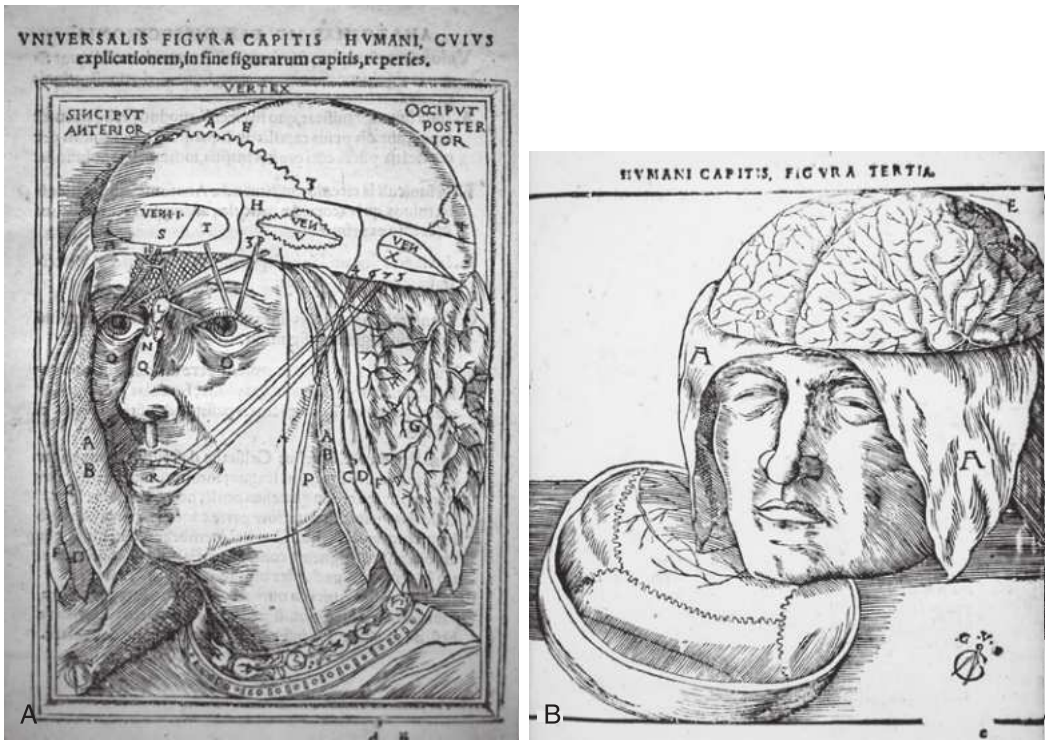
Berengario, besides being a skilled surgeon, was also an excellent anatomist. Through Berengario we are provided with one of the earliest and most complete discussions of the cerebral ventricles. From his anatomic studies Berengario developed descriptions of the pineal gland, choroid plexus, and lateral ventricles. His anatomic illustrations are believed to be the first published from actual anatomic dissections rather than historical caricatures. Of enormous significance for this period were his anatomic writings, which were among the earliest to challenge the dogmatic beliefs in the writings of Galen and others.

An important book, *Anatomiae*, is most likely the earliest to deal with "accurate" neuroanatomy and appeared in 1536 (with an expanded version in 1537). The book was written by a professor of medicine from Marburg, Johannes Dryander (Johann Eichmann, 1500–60).[48,49] This work contains a series of full-page plates showing successive Galenic dissections of the brain (Fig. 1.21). Dryander starts with a scalp dissection in layers. He continues a series of "layers," removing the skullcap. He next illustrates the meninges, brain, and posterior fossa. The first illustration of the metopic suture appears in one of the skull figures. Important to Dryander's studies was the performance of public dissections of the skull, dura, and brain, the results of which he details in this monograph. One image depicts the ventricular system and the cell doctrine theory in which imagination, common sense, and memory are placed within the ventricles. There are a number of inaccuracies in the work, reflecting medieval scholasticism, but despite these errors this book should be considered the first textbook of neuroanatomy.

Volcher Coiter (1534–76) was an army surgeon and city physician at Nuremberg who had the good fortune to study under Fallopius, Eustachius, and Aldrovandi. These scholars



• **Figure 1.20** (A) Woodcut device from the title page of Berengario da Carpi's *Tractatus de Fractura Calvae.* (B) Berengario's design for a trephine brace. (C) Berengario's trephines reveal a number of sophisticated designs for bone cutting and angles to avoid plunging into the brain. (From Berengario da Carpi J. *Tractatus de Fractura Calvae Sive Cranei.* Bologna: Hieronymus de Benedictus; 1518.)



• **Figure 1.21** (A) Illustration from Dryander's *Anatomiae* showing his layered dissection of the scalp and head. Also illustrated is the cell doctrine theory in which function of the brain rested in the ventricular system, not in the brain. (B) Illustration from Dryander's *Anatomiae* showing a dissection of the scalp, skull, and brain plus the skull sutures seen in the skullcap. (From Dryander J. *Anatomiae.* Marburg: Eucharius Ceruicornus; 1537.)

provided the impetus for Coiter's original anatomic and physiologic investigations. He described the anterior and posterior spinal roots and distinguished gray from white matter in the spinal cord. His interest in the spine led him to conduct anatomic and pathologic studies of the spinal cord, including a study on the decerebrate model. He performed a number of experiments on living subjects including work that predated William Harvey on the beating heart. He trephined the skulls of birds, lambs, goats, and dogs and was the first to associate the pulsation of the brain with the arterial pulse. He even opened the brain and removed parts of it, reporting no ill effects—an early, surprising attempt at cerebral localization.[50] Because of his enthusiastic anatomic studies via human dissection, he ran afoul of the Inquisition and ended up being jailed by the Counter-Reformation, which held great distrust of physicians and anatomists who were challenging already accepted studies.

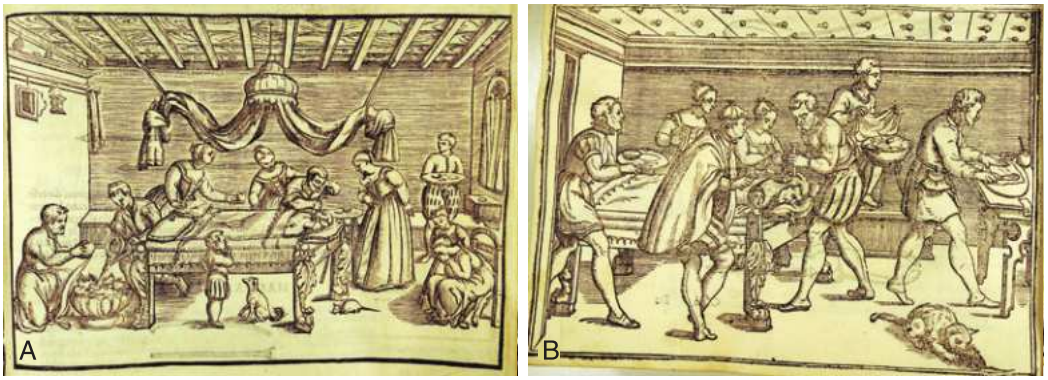
Using a combination of surgical skill and a Renaissance flair for design, Giovanni Andrea della Croce (1509?–80)[51] produced some very early engraved scenes of neurosurgical operations. The scenes are impressive to view, as the surgeries were performed in family homes, typically in the bedrooms. Most of the neurosurgical procedures illustrated were trephinations (Fig. 1.22). Croce also provides a series of newly designed trephines with safety features to prevent plunging. An unusual innovation involved his trephine drill, which was rotated by means of an attached bow, copying the style of a carpenter's drill. Various trephine bits with conical designs are proposed and illustrated. Included in his armamentarium are illustrations of surgical instruments that include some cleverly designed elevators for lifting depressed bone. In reviewing Croce's book we find it is mainly a compilation of earlier authorities from Hippocrates to Albucasis, but his recommendations for treatment and his instrumentation are surprisingly modern.

A discussion of surgery in the 16th century would not be complete without mention of the great anatomist and surgeon Andreas Vesalius (1514–64). Clearly a brilliant mind, he early on rejected the anatomic views of his Galenic teachers. Vesalius studied in Paris under Johann Günther (Guenther) of Andernach, an educator of traditional Galenic anatomy. Günther quickly recognized Vesalius' skills and described him as a gifted dissector, one with extraordinary medical knowledge, and a person of great promise. Despite the laudatory praise, Vesalius quickly came to the conclusion, from his Paris medical studies, that many errors in basic anatomy existed. Following the theme of earlier 16th-century anatomists such as Berengario da Carpi, Vesalius strongly argued that anatomic dissection must be performed by the professor, not by prosectors. The common practice was to have a prosector, typically an uneducated surgeon, probe the body under the direction of the professor, who read from a Galenic anatomic text. Errors of text that did not agree with the dissection findings were merely overlooked. Vesalius' anatomic descriptions came from his own observations rather than an interpretation of the writings of Galen and others. Considering the staunch orthodox Galenic teaching of the time, he clearly faced some serious opposition from his teachers.

Vesalius's anatomic studies culminated in a masterpiece, *De Humani Corporis Fabrica*, published in 1543.[52] In Book VII is the section on the anatomy of the brain that presents detailed anatomic discussions along with excellent engravings (Fig. 1.23). Vesalius noted that "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."[53]

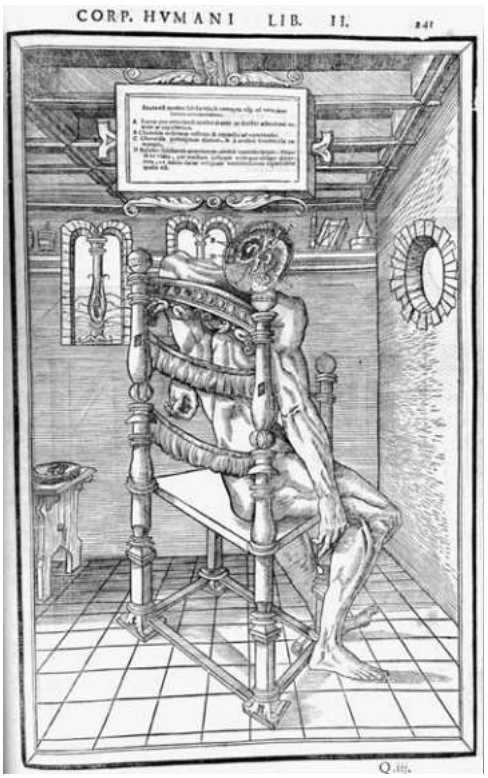
Vesalius was primarily a surgeon, and the section of text on the brain and the dural coverings discusses mechanisms of injury and how the various membranes and bone have been designed to protect the brain.[53] Interestingly, close examination of several of the illustrated initial letters in the text shows little cherubs performing trephinations! For neurosurgeons Vesalius made an interesting early contribution to the understanding of hydrocephalus: In Book 1 is a discussion of "Heads of other shape" wherein he provides the following early description of a child with hydrocephalus:

> [A]t Genoa a small boy is carried from door to door by a beggar woman, and was put on display by actors in noble Brabant in Belgium, whose head, without any exaggeration, is larger than two normal human heads and swells out on either side.[52]



• **Figure 1.22** (A) A classic scene of a 16th-century Renaissance trephination being performed in a noble's elegantly furnished bedroom, complete with pet dog and child at bedside, from Croce's classic monograph on surgery. (B) An Italian surgeon performing a burr hole with his assistants and instruments surrounding him. (From Croce GA della. *Chirurgiae Libri Septem.* Venice: Jordanus Zilettus; 1573.)

• **Figure 1.23** Portrait of the great anatomist Andreas Vesalius demonstrating a dissection of the arm from his *magnum opus.* (From Vesalius A. *De Humani Corporis Fabrica Libri Septem.* Basel: Joannes Oporinus; 1543.)



• **Figure 1.24** A neuroanatomic plate from Estienne's *De Dissectione* showing an axial dissection of the brain of a man seated in a sumptuous room in a villa. (From Estienne C. *De Dissectione Partium Corporis Humani Libri Tres.* Paris: Simon Colinaeus; 1546.)

In the second edition (1555) of his work,[54] Vesalius describes a second case, that of hydrocephalus in a young girl whom he noted to have a head "larger than any man's," and at autopsy he describes the removal of 9 lb of water. As a result of these studies Vesalius made the important observation that fluid (ie, cerebrospinal fluid) collects in the ventricles and not between the dura and skull, an earlier Hippocratic error. Vesalius made a number of interesting clinical observations but offered no insight into any effective treatment, either surgical or medical.

A remarkable work on anatomy by Charles Estienne (1504–64) appeared in Paris in 1546.[55] This book was the fifth in a series of books on anatomy to be published in Europe, following Berengario da Carpi (two books), Dryander, and Vesalius. Although published 3 years after Andreas Vesalius' work, the book had actually been completed in 1539, but legal problems delayed publication. This work contains a wealth of beautiful but bizarre anatomic plates with the subjects posed against sumptuous, imaginative Renaissance backgrounds (Fig. 1.24). The anatomic detail clearly lacks the details of Vesalius and the book repeats many of the errors of Galen. The plates on the nervous system are quite graphic but flawed in the anatomic details. A typical plate shows a full anatomic figure with the skull cut to show the brain. Although gross structures like the ventricle and cerebrum are recognizable they do lack solid anatomic details.

With the end of the 16th century anatomy has come full circle, rejecting earlier doctrines flawed with numerous errors. In works by Vesalius and Berengario hands-on dissection by the professor clearly corrects many of the anatomic errors long ensconced in the literature. Without these fundamental changes in both thought and concept, the development of neuroanatomy would not have been possible. Without accurate neuroanatomy, how can one practice neurosurgery? As we will see, nearly 300 more years of surgical art, skill, and anatomy are needed to let that happen.

Seventeenth Century: Origins of Neurology

In the 16th century anatomy was the main theme, and with the 17th century we see the development of a period of spectacular growth in science and medicine. Individuals such as Isaac Newton, Francis Bacon, William Harvey, and Robert Boyle made important contributions in physics, experimental design, the discovery of the circulation of blood, and physiologic chemistry. For the first time open public communication of scientific ideas came with the advent of scientific societies (eg, the Royal Society of London, the Académie des Sciences in Paris, and the Gesellschaft Naturforschenden Ärzte in Germany). These societies and the individuals associated with them dramatically improved scientific design and education along with unparalleled exchanges of scientific information.

Within this century came the first intense exploration of the human brain. Leading the many investigators was Thomas Willis (1621–75), after whom the circle of Willis is named