The management of cranial injuries in antiquity and beyond

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✓Cranial injuries were among the earliest neurosurgical problems faced by ancient physicians and surgeons. In this review, the authors trace the development of neurosurgical theory and practice for the treatment of cranial injuries beginning from the earliest ancient evidence available to the collapse of the Greco–Roman civilizations. The earliest neurosurgical procedure was trephination, which modern scientists believe was used to treat skull fractures in some civilizations. The Egyptian papyri of Edwin Smith provide a thorough description of 27 head injuries with astute observations of clinical signs and symptoms, but little information on the treatment of these injuries. Hippocrates offered the first classification of skull fractures and discussion of which types required trephining, in addition to refining this technique. Hippocrates was also the first to understand the basis of increased intracranial pressure. After Hippocrates, the physicians of the Alexandrian school provided further insight into the clinical evaluation of patients with head trauma, including the rudiments of a Glasgow Coma Scale. Finally, Galen of Pergamon, a physician to fallen gladiators, substantially contributed to the understanding of the neuroanatomy and physiology. He also described his own classification system for skull fractures and further refined the surgical technique of trephination. From the study of these important ancient figures, it is clearly evident that the knowledge and experience gained from the management of cranial injuries has laid the foundation not only for how these injuries are managed today, but also for the development of the field of neurosurgery. *(DOI: 10.3171/FOC-07/07/E8)*

KEY WORDS • head injury • history of neurosurgery • intracranial pressure • skull fracture • trephination

CRANIAL INJURIES were among the earliest neurosurgical problems faced by ancient physicians and surgeons. Prior to advances in the understanding of neuroanatomy, physiology, and localization, few true neurological symptoms appeared to localize to the brain. Therefore, symptoms such as paresis, paresthesia, spasticity, vomiting, and blurry vision would all appear to be problems associated with their respective organs rather than with the brain. As a result, direct injury to the cranium was one of the few recognized neurological conditions. Many of the ancient surgeons learned and practiced on the battlefield, where the acute state of injury necessitated urgent and at times drastic interventions. Thus, when studying the evolution of cranial injury management, one can obtain a glimpse of the origins of neurosurgery.

In this paper, the authors trace the development of neurosurgical theory and practice for the treatment of cranial injuries, from the earliest ancient evidence available to the collapse of the Greco–Roman civilizations. Although some overlap exists, this time span can be broken down into several major movements according to date and geographic location: 1) the Neolithic period, circa 10,000 to 1000 BC; 2) the Egyptian period, circa 3000 to 600 BC; 3) the Greek period, circa 600 BC to 0; 4) the Alexandrian era, circa 330 BC to AD 100; and 5) the Roman era, circa AD 100 to 500.

The Neolithic Period: The First Discoveries

The earliest evidence of neurosurgical practice is a trephinated skull that dates back to 10,000 BC at the beginning of the Neolithic period. The term "trepanation" has its etymological roots from the word "trypanon," a Greek word meaning an "auger or a hand tool for boring holes."[9] The term "trephination" also refers to the removal of portions of bone from the skull, but is used in relation to the later developed trephine, a type of circular saw.[1,34] Evidence of the practice of trephination has been discovered by archeologists all over the world including modern Europe (France, Spain, Portugal, Germany, Czechoslo-

Abbreviations used in this paper: CSF = cerebrospinal fluid; ICP = intracranial pressure.

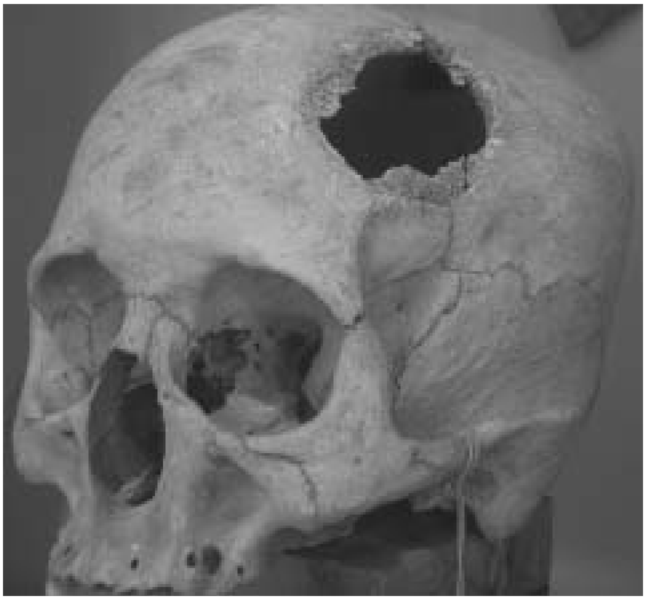

FIG. 1. Photograph of an ancient skull found in a tomb at Paracas, Peru, circa 2000 BC. The trephining hole in the left frontoparietal area shows new bone formation at the edges, providing evidence that the patient survived the procedure. Photograph reproduced courtesy of the International Museum of Surgical Science, Chicago, Illinois.

vakia, Scotland, Denmark, Sweden, Austria, Poland, and Italy), North America (Canada and the US), Central America (Mexico), South America (Peru, Bolivia, and Columbia), Africa, and Asia.[8,10,14,17,18,21,24,25,31,34,36] The evidence from the Neolithic period exists not in any written form, but in fossilized skulls and surgical tools discovered during archeological excavations. Thus, through the obscurity of a modern interpretation, one is forced to deduce the techniques, indications, and relative successes of these procedures.

There were four primary techniques used for trephining during this period: 1) scraping the bone down to the dura; 2) making four perpendicular cuts to remove a square piece of bone; 3) creating a circular groove around the piece of bone to be removed; and 4) creating a series of small holes in a circular fashion, and then connecting the holes to excise the central piece of bone.[15,20] In the early and middle Neolithic period, sharp stones were used as surgical instruments. Over time these stone instruments became more refined in shape, and near the end of this period they were made from bronze.[1,15,19,35]

It is unclear what anesthetic agent, if any, was used during these procedures. Some scholars suggest that the Peruvians used leaves of the coca plant;[12,31] other possibilities include alcohol, Mandragora plants, and opium. It is also just as likely that no anesthetic was used—the study of 20th-century east African tribes that still practiced trephination revealed that they did so without anesthetics.[1,23]

Even more impressive than the courage to perform these early procedures was the fact that many people survived, which is apparent if the edges of the hole show evidence of bone regrowth. Of the 400 Peruvian skulls studied by Julio C. Tello (now at the Warren Museum of Harvard Medical School), 250 show evidence of cicatrization, strongly suggesting that more than 50% of patients survived (Fig. 1).[31,35] This study may underestimate the survival rate because in Peru it appears that the procedure was mainly performed for cranial trauma and many patients may have died due to their primary injury rather than the surgical intervention. Additionally, one must consider the possibility that practitioners of trephination may have performed the procedure postmortem, giving the impression of death by surgical intervention. The 20th-century east African tribes had mortality rates of only 5% after this procedure.[1]

As previously noted, there is no written evidence from this prehistoric period, leaving modern scientists to deduce the indication for performing the procedure from fossils. Therefore, a brief description of modern theories that scientists have given for the indication of trephination is required (Fig. 2). Barthélemy Prunières discovered one of the earliest collections of skulls during his excavations of the granite dolmens (stone tables) in central France.[7,28,29] This collection of skulls from France has been estimated to be between 4000 and 5000 years old. This collection was studied extensively by Prunières and Paul Broca shortly after their discovery, followed by Victor Horsley some years later. Each major figure posited differing theories as to why these procedures were performed and in

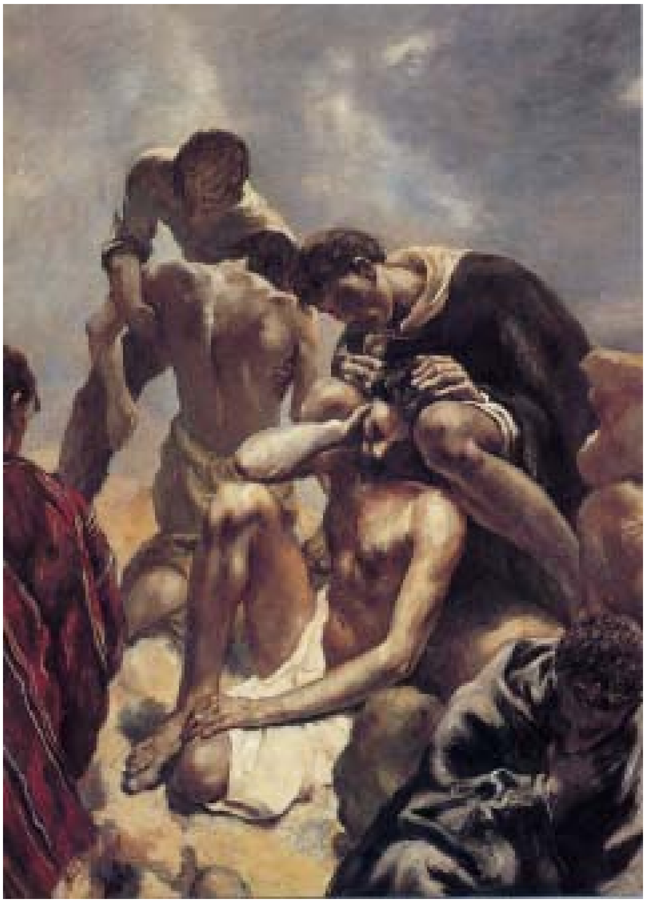

FIG. 2. Painting depicting an early trephining procedure, possibly on a soldier that had sustained a cranial injury. Painting reproduced courtesy of the International Museum of Surgical Science, Chicago, Illinois.

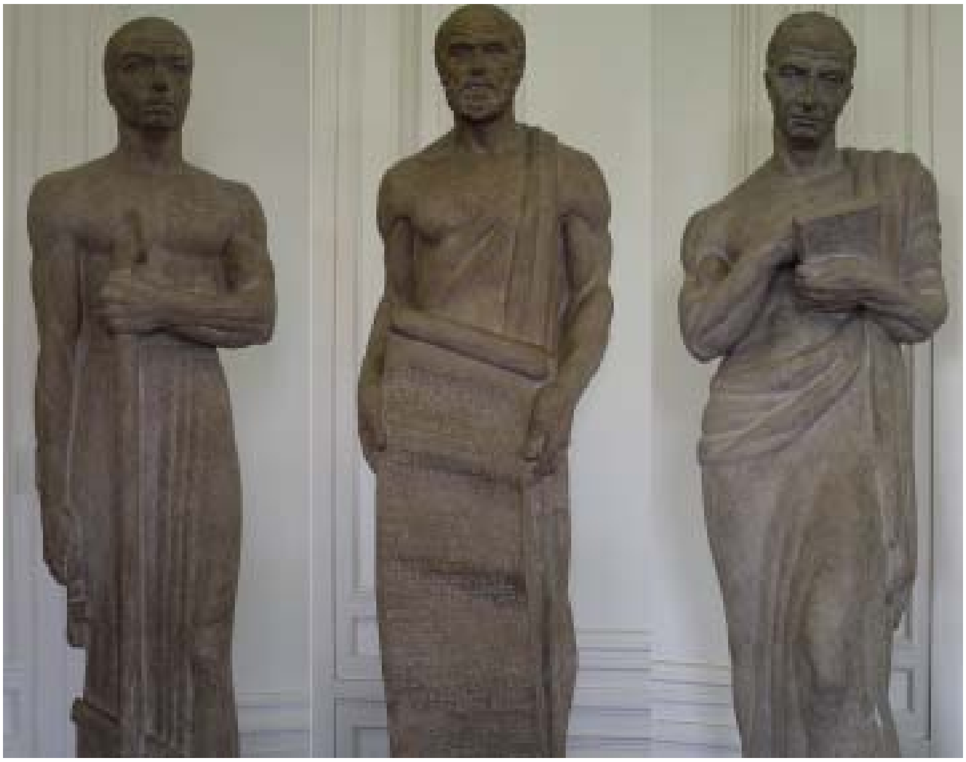

FIG. 3. Photographs of statues representing important ancient physicians. *Left:* Imhotep, Egyptian physician to the Pharaoh. *Center:* Hippocrates holding a scroll containing the original Hippocratic Oath. *Right:* Galen, Roman physician to the gladiators. Photographs reproduced courtesy of the International Museum of Surgical Science, Chicago, Illinois.

what types of patients. The theories of both Prunières and Broca are thoroughly well described by Clower and Finger.[7]

According to these authors, Broca believed that trephination was performed almost exclusively on infants because several early samples he studied demonstrated deviated suture lines near the site of trephination. Broca believed that the indication for trephination was primarily benign infantile convulsions, for which trephination supposedly released evil spirits from the brain, while simultaneously producing the illusion of a surgical cure. Adding to the spiritual aspect of the practice in France, the excised portions of bone, termed "roundelles," were often worn due to a spiritual significance they must have contained.[1] Broca rejected the idea that the procedure was performed to excise fractured segments because the French collection did not demonstrate evidence of nearby fracture sites, nor was there a preponderance of male skulls, left-sided holes (from an attack by right-handed enemy), or frontal holes (from an attack from the front)—all of which one could expect if the holes were at fracture sites sustained in battle. In addition, Broca experimented with corpses and found that it took merely 4 minutes to scrape a hole in the skull of a 2-year-old child compared with 50 minutes in an adult; this difference was formidable in an age prior to the advent of general anesthetics.[4] Buckland,[5] among others, has discredited this idea by noting that some infants must have been immediately killed by the procedure, yet the Prunières collection contained no infantile skulls with evidence of trephination.

Twelve years after Broca's investigation, Horsley studied the Prunières skulls in Paris and came to the conclusion that the procedure was performed for posttraumatic seizures after cranial fractures. Horsley was convinced that the openings were frequently placed over what he believed was the motor cortex.[16] The US archeologist Ephraim George Squier and researcher Josiah Nott both also believed that trephination was performed for cranial fractures; however, both of them studied Peruvian skulls, which, unlike the French collection, exhibited evidence of fracture lines in close vicinity to the trephination sites.[17,32] In addition, the Peruvian skulls have a preponderance of openings in the left temporoparietal region, likely indicative of blows from right-handed assailants.[1] Tello's study of Peruvian skulls lead him to believe that cranial fractures were the primary indication for trephination.[31,35] The Peruvian skulls from the Incas are estimated to be less than 2500 years old, whereas the skulls found in France and other areas of Europe are estimated to be between 4000 and 5000 years old.[7] Thus, it is probable that these viewpoints are not conflicting, but simply represent distinct practices arising from different geographic locations and time periods. This concept is further supported by study of 20th-century east African tribes, which revealed that trephination was performed for varying purposes—the Kisii tribe used it to relieve headache after cranial injury, whereas for the Lugbara tribe the purpose was to release evil spirits.[1,23] Although there is well-established evidence that trephination was performed for skull fractures in at least some instances, there is no further knowl-

FIG. 4. Photographs of surgical instruments described by Galen. *Upper*: Bone forceps used to remove pieces of bone fragments from comminuted fractures. *Lower*: Bone elevator with a blunt underside used to elevate depressed fractures while protecting underlying parenchyma. Photographs reproduced courtesy of the International Museum of Surgical Science, Chicago, Illinois.

edge of the management of cranial injuries during this time period.

The Egyptian Period

Elliot Smith, a professor in Cairo, found no evidence of trephined skulls after having studied nearly 15,000 skulls in Egypt in the early 1900s.[31,33] The first written evidence of medicine comes from the Egyptian Ebers papyrus, written circa 1500 BC. Papyri were stems of water plants used by Egyptians on which they could write and paint. The Ebers document, unfortunately, contains little of surgical interest. The Edwin Smith papyri, named after the American Egyptologist who purchased them in Luxor in 1862,[1] contain discourses on surgical and even neurosurgical ailments. Of note, Breasted believes that these papyri may be a copy of another dating as far back as 3000 BC because the 1700 BC version is supplemented with commentary on words that could not have been familiar to the common Egyptian at that time.[3,31]

The treatise contains elegant descriptions of 48 cases, including cranial and spinal injuries. In particular, it describes 27 head injuries, including superficial lacerations. There are descriptions of four deep scalp wounds exposing the skull and 11 skull fractures. According to neurosurgeon and historian Gilbert Horrax,[15] if these 11 fractures were classified in modern terminology, there would be two compound linear fractures, four compound depressed fractures, four compound comminuted fractures, and one comminuted fracture with a minimal external wound.

The descriptions in the Edwin Smith papyri demonstrate astute and thorough observation and use of all five senses. Additionally, they contain the first written description of the convolutions of the brain and the meninges. In fact, it is here that we find the first use of the term "brain." The papyri describe injuries to the cervical spinal cord causing persistent erections, seminal emissions, and urinary retention. A wound to the crown of the head is compared to the smell of the urine of sheep, which perhaps could have indicated a specific type of infection present at the time.[31] A "feeble pulse" and fever were recognized as indicating hopeless injury, the former most likely indicating cardiovascular collapse from brainstem damage or severe hypovolemia from hemorrhage, and the latter possibly referring to secondary infection. Deafness and aphasia are associated with severe temporal bone fractures, likely referring to damage to Heschl's gyrus in the former, and Broca's area, Wernicke's area, and its connecting arcuate fasciculus in the latter.[15] Also crucial to the management of cranial injuries is the first description of the concept of triaging patients by classifying their treatments as either "An ailment which I will treat, an ailment with which I will contend, [or] an ailment not to be treated."[3,15]

For treatment of superficial wounds, suturing as well as types of adhesive tapes taken from embalmers were used to approximate wound edges. A sitting position was advocated for temporal bone fractures and bandaging was to be avoided for compound skull fractures, likely to prevent anaerobic infection. According to the translation by Breasted, there is no mention in the Edwin Smith papyri of trephination as a treatment for skull fractures.[3] As stated, there is no archeological evidence of trephined skulls found in Egypt, except for one found by Hrdlicka that was reported to Breasted.[3,15] Nonetheless, the Edwin Smith papyri stand as an impressive contribution to the early study of cranial injury.

Other great civilizations that flourished in this era included the Sumerians, Babylonians, and Assyrians, although there are very few documents demonstrating their knowledge. Yet we do know that surgical practice existed, as evidenced by the Hammurabi code (2000 BC), which states:[26] "If a surgeon causes a severe wound with a bronze knife and cures his patient, he shall have 10 shekels of silver. If a surgeon causes a severe wound and the patient dies he shall have his hands cut off." This statement also demonstrates that it did not take very long from the beginning of medicine for malpractice law to follow!

The Greek Era

The beginnings of the Greek era lacked any substantial evidence of neurosurgery. The early period was dominated by the physician Asclepius, who like the Egyptian physician to the Pharaoh Imhotep (Fig. 3, *left*), was deified upon his death. Both of these figures were part of an era that predominantly viewed disease in terms of supernatural causes. Thus, if one became ill, it was because he or she displeased the gods or was a captive of an evil spirit. As Greek philosophy began to flourish, one figure emerged to apply the powers of reason and observation to medicine. Hippocrates (460–370 BC) is often dubbed the father of

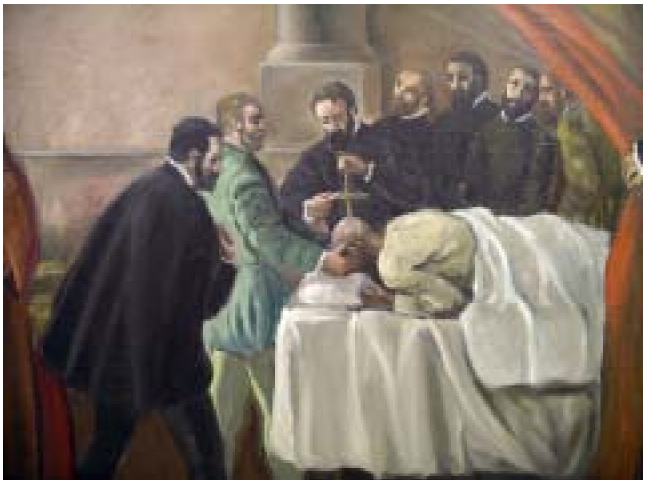

FIG. 5. Painting depicting a more advanced trephining procedure in Spain during the 16th century. Note that this procedure is being performed in an operating room and with more advanced instruments, but still lacks sterile techniques. Painting reproduced courtesy of the International Museum of Surgical Science, Chicago, Illinois.

the medical profession because he transformed it from a practice assumed by individual spiritual figures into a profession bound by a code of ethics, the Hippocratic Oath (Fig. 3, *center*). Hippocrates was also the first to reject the prior view of disease and instead advocate a causal system of natural imbalances. Thus, if one was sick, it was because he or she had an imbalance of the four main bodily fluids: yellow bile, black bile, blood, and phlegm. From this theory came the practice of bloodletting that was performed by surgeons for more than 2000 years.

The Greeks frequently engaged in warfare, and thus there were ample opportunities for physicians of that era to learn and develop theories of management for head injuries. As Hippocrates once said, "War is the only real school for the surgeon."[37] Hippocrates noted that certain areas, specifically the bregma and temporal fossa, were the most vulnerable to damage and that areas such as the occiput were rarely affected.[31] He also realized that injury was much more severe if the dura mater had been penetrated—as one would assume due to increased risk for parenchymal injury, bleeding, CSF leak, and infection. In his written work, Hippocrates developed a classification of cranial injuries and described which types required operative treatments. The five types of skull fractures were as follows:[13,15,31] 1) fissure (always accompanied by contusions of the brain); 2) contusions of bone without fractures; 3) depressed fracture (fracture of inner table and depression of the outer table); 4) impressions on the skull (indentation on outer table of skull without damage to inner table or penetration of the skull); and 5) fractures at sites other than the site of direct injury (countercoup injuries).

The practice of trephination was already well established and was advocated by Hippocrates and other Greek physicians for certain types of head injuries. The following passage is taken from Hippocrates' discussion on the indication for trephination for head injuries:[13]

> Of these modes of fracture the following require trepanning: the contusion, whether the bone be laid bare or not, and the fissure, whether apparent or not. And if, when an indentation by a weapon takes place in a bone it be attended with fracture and contusion, and even if contusion alone, without fracture, be combined with the indentation, it requires trepanning. A bone depressed from its natural position rarely requires trepanning.

Hippocrates recommended trephination for all skull injuries except for depressed fractures, which is surprising and contrary to many physicians before and after him. He also avoided surgery for extensively comminuted fractures. It appears that Hippocrates understood the basis of the Monroe–Kellie doctrine because he advocated trephination to "slacken the tightness of the head" in cases of intracranial bleeding, inflammation, and for the removal of foreign bodies.[2,13] He was also aware of infection of the bone from inflammation of the soft parts and he advised an incision of the scalp likely for drainage and the use of drying applications.[15,31] Of note, although ancient surgeons recognized pus as a deleterious process and were astute enough to realize the necessity of drainage, it is highly unlikely that they understood the etiology of infection because microbiology theory was absent until the work of Pasteur, Lister, and Semmelweis in the mid 1800s, the golden age of microbiology.

Hippocrates described three appearances of skull suture lines in the shape of the Greek letters χ (Chi), τ (tau), and ι (iota).[31] He observed that deep wounds on the left side of the skull sometimes caused convulsions or paralysis on the contralateral side of the body and vice versa.[2] Hippocrates also recognized that trephination could be used effectively to treat vision loss from an intracranial source. He states that "When sight fails without apparent disease of the eyes an incision should be made in the parietal region, the soft parts reflected, the bone trephined and the fluid beneath let out—that is the treatment, and it is thus these patients get well."[2] It is likely that Hippocrates is describing vision loss from increased ICP (the causes of which are certainly not limited to cranial injury) rather than cortical blindness, and by trephining he opened the dura and drained CSF to relieve pressure on the optic apparatus.

Even more remarkable than Hippocrates' apt observations are his detailed descriptions of the technique of trephination. The particular trephination instruments used during this time are well described elsewhere.[6,15,27] In cranial injuries, Hippocrates stressed the importance of meticulous investigation of wounds: bones were carefully scraped to look for any fractures lines and dyes were also used to help highlight bone fracture lines and determine their depth.[11] Lacerations were often extended to open any pockets that could serve as a habitat for pus. Although it is not clear who invented the newer trephines, it was during this time that these instruments used protective collars to avoid dural penetration when boring through skull bone. Hippocrates advised that in the process of creating a hole, one needed to frequently stop and investigate the area to make sure the dura had not been penetrated. Although the texts state that the dura was not to be penetrated, in cases of increased ICP, it is doubtful that much decompression could be achieved without opening of the dura. Perhaps experience revealed that dural penetration resulted in extremely high rates of infection in addition to risks of bleeding, CSF leakage, and parenchymal injury, which then led to higher mortality rates.

Hippocrates also stated that a trephine should never be used over a suture line, although he does not state why.[30,31] It is suggested that perhaps he observed from experience that the dura is more adherent at suture lines or perhaps he shared Galen's view that sutures were involved in a kind of respiratory exchange.[31] Perhaps Hippocrates originally meant to state that suture lines should not be confused with fractures and therefore trephined. Hippocrates also warns against holes made in the temporal bone, as one may inadvertently injure the "temporal artery," which he states would cause convulsions. Because the superficial temporal artery in modern terminology supplies the scalp, it is likely he was referring to the middle meningeal or perhaps even the middle cerebral vessel branches.[31]

Alexandrian Contributions

The death of Hippocrates in 370 BC coincided with a time of decline in Greek medicine. The Egyptian city of Alexandria was founded by the conqueror Alexander in 331 BC, although he died less than a decade later. It was here that the Alexandrian school flourished between the time of Hippocrates and Galen. The two well-known professors leading the scholarly work were Herophilus of Chalcedon (335–280 BC) and Erasistratus of Chios (310–250 BC). Unfortunately, much of the written work from that time period has been lost. Our primary record of the Alexandrian school comes from the scientist Aulus Aurelius Cornelius Celsus (25 BC–AD 50). Because he was not a physician himself, his writings likely reflect the findings of the Alexandrian school. The observations of clinical signs and symptoms made by these physicians in cases of head injuries were very impressive. Celsus states:[6]

> Therefore after a blow on the head first we must inquire whether the patient has had bilious vomiting, whether there has been obscurity of vision, whether he has become speechless, whether he had had bleeding from the nose or ears, whether he fell to the ground, whether he has lain senseless as if asleep; for such signs do not occur unless with fractured bone; and when they are present, we must recognize that treatment is necessary but difficult. If in addition there is also stupor, if the mind wanders, if either paralysis or spasm has followed, it is probable that the cerebral membrane has also been lacerated.

In this wonderful quotation, Celsus describes signs of increased ICP (vomiting, blurred vision), which can occur after injury with or without skull fracture. He describes symptoms that would lead one toward a diagnosis of a basilar skull fracture (bleeding from the ears or nose). Loss of consciousness can occur after head trauma with increased ICP, concussion, or diffuse axonal injury. Additionally, focal paralysis or spasms could indicate direct parenchymal injury, as Celsus states, but it could also result from mass effect. By integrating cognitive, motor, and speech abilities in his assessment of head trauma patients, Celsus incorporates all of the basic aspects of the modern Glasgow Coma scale. One can easily appreciate the intelligence of these observations at a time period nearly 2000 years before theories of cerebral localization.

Celsus recognized the different types of fractures as elaborated by Hippocrates, but unlike his predecessor, he advocated trephination for depressed fractures to elevate or remove fragments to allow room for inflammation. He also advocated trephination when patients developed symptoms after trauma despite the absence of any fracture: "It sometimes . . . though rarely happens that the bone remains intact, and that owing to a rupture of a vessel of the dura mater blood is effused beneath the bone, and there coagulates and causes great pain and dimness of vision. Nearly always the pain is over the site of the clot, and here the bone should be trephined."[2,6]

It appears that here Celsus describes the situation of traumatic hemorrhage whether it is subdural, epidural, or subarachnoid (although the latter seems less likely as the primary hemorrhage source, given that Celsus prescribes the evacuation of localized clot formation over the trauma site). Certainly, the Alexandrian school of thought should be recognized for its contributions to the understanding of neurosurgery and particularly the management of head injuries. The Alexandrian school also provided a progressive link to the next great figure in medical history—Galen.

The Roman Era

As the Roman Empire emerged in the 2nd century AD, so did Galen arise in the field of medicine. Galen of Pergamon (AD 129–200) was a physician who primarily learned medicine by caring for the gladiators in Rome (Fig. 3, *right*). Thus, he had ample opportunities to study head injury. Galen's contributions to neuroanatomy, neurosurgery, and physiology are immense, as evidenced by the voluminous collection of writings he generated. He was the first to describe the cerebral aqueduct (later named the aqueduct of Sylvius), cranial nerves and their functions (specifically the facial and trigeminal nerves), the condition of hydrocephalus, and the dependency of muscle function on the supply of nerves.[1,31] His anatomical work was primarily conducted on pigs and apes because the dissection of human bodies was forbidden in his era; however, it was rumored that he sent his students to Germany to dissect the bodies of fallen enemies in battle and report back to him.[2]

Galen described his own classification of skull injuries and advocated trephination for depressed fractures, fractures with hematoma (although he did not specify the type of hematoma), separated and elevated fragments (comminuted), and trichiasis (superficial gouging of the bone).[31] Galen also advocated removal of bone if there was suspected pus collection under the skull and also for contusion without fracture, presumably for the same reason Hippocrates provided.[15] Unlike Hippocrates, Galen advocated as a rule that all extensively comminuted fractures should be removed entirely.[27] Whenever possible, Galen preferred to remove skull fragments with a bone forceps device to avoid damage to underlying structures (Fig. 4, *upper*). From Galen we have the one of the most detailed descriptions of the technique of trephination.

Galen frequently used the trephining technique that had been passed down to him. The area of bone to be removed would be surrounded on the periphery with small-trephined perforations. The holes would then be united by removing intervening bone with a mallet and chisel. The second method used was to create a single central hole using the trephine, then to work radially using a mallet and chisel to enlarge the hole.[15] Galen stressed care and caution during trephination, such as to frequently remove the trephine and inspect the inner table of bone. Galen also described a technique for treating the trephined wound. He applied "dressings of wool with oil of roses next to the dura" while exerting care not to put any pressure on the dura.[15] Galen also illustrates cerebral herniation through the trephined hole, a possible complication of the procedure for which he says nothing could be done.

Besides technique, Galen also describes many innovations in the instruments used for the procedure, but it is unclear what was actually designed by him. He described an "auger which will not plunge in" by having a raised ring around the cutting device to allow the device to drill a hole of a certain distance only, thereby avoiding damage to underlying brain structures.[15, 22] He also described the "μενινγοφνλαζ," which was a dissector used to lift depressed fractures that had a blunt edge to protect the underlying parenchyma (Fig. 4, *lower*).[15,22]

Heliodorus (circa AD 100), one of Galen's contemporaries, also studied and wrote about cranial injuries. Much of what he writes is in agreement with Galen in regard to the indications for operation and the technique of trephination. Heliodorus adds elegant illustrations of the surgical approach and preparation of patients in terms of positioning of the patient and operators depending on the location of cranial injury. Interestingly, he also notes that the patient's ears should be "stopped up" so that the patient does not hear the noise of bone removal, which would certainly generate anxiety and panic in a patient who had not received anesthesia. Additionally, Heliodorus stated that it was not necessary to bind the patient down with ropes because bone was not sensitive. Surely Heliodorus must have referred to cases where the bone was already exposed because the scalp is one of the most sensitive areas in the body. The exception Heliodorus notes is if there is comminution with depression causing irritation of the dura.[15]

The ideas of this period, in particular the writings of Galen, represented the pinnacle of medical and surgical theory in the ancient world and would exert a dominance in the field of medicine for the next 1000 years.

The Medieval Period

According to the available evidence, intellectual stagnation blanketed the Greco–Roman world after the disintegration of the Roman Empire. Prior to the fall of the empire, the Nestorians were banished from Constantinople for views of Jesus that were denounced as heresy during the 4th century AD. Rulers of the Sassanid Empire welcomed the exiles and, as a result, many of the best Greek and Roman works were translated into Persian, and Greek and Roman knowledge began to disseminate to Persia. In addition to some of their own contributions, the Arab world has been recognized for preserving the medical knowledge of the Greeks and Romans through the medieval period. Yet very little knowledge was added to the neurosurgical management of cranial injuries until the medical school in Salerno, Italy, regenerated interest in cranial surgery in the 11th century. Increased understanding of neuroanatomy, physiology, neuropathology, and surgical techniques during the Renaissance led to the rapid advances of the modern era (Fig. 5).

Conclusions

Cranial injuries are among the earliest neurosurgical problems that faced the ancients, in part because of the close relation between early surgery and battlefield injuries. The most prominent medical figures during this time used astute observation of clinical signs and symptoms to diagnose and prognosticate outcomes of cranial injuries. They were the first to realize that cranial injuries could manifest symptoms in all parts of the body. Through these observations, the ancients laid the foundation for neuroanatomy and physiology. They were the first to understand the concept of increased ICP, and they realized that surgical decompression was sometimes required. They classified skull fractures and described indications for operative treatments. Through experience, reasoning, and likely trial and error, early forms of both medical and surgical treatment were developed. Trephination was among the primary treatments for skull fractures and, with time, ancient surgeons developed more precise indications and refined techniques for the procedure. It is clearly evident that the knowledge and experience gained from the management of cranial injuries has laid the foundation not only for how these injuries are managed today, but also for the development of the field of neurosurgery.

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