Original Article

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Landmarks in the Traumatic Brain Injury: A Retrospective Study

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Abstract

As one might expect, prehistoric brain surgery lacked knowledge of the anatomy, concept recognition of the disease, and comprehension of the disease's origin. Unfortunately, failure to deeply understand these important principles delayed the progression of medical and surgical practice. Trepanation may be one of the oldest surgical interventions for which archaeological evidence is present. In the 1990s, standardized guidelines were developed and established for the management of traumatic brain injury. They included protocols regarding the pharmaceutical therapy and the management of increased ICP. Since then, research has improved TBI survival. Evidence of trepanation practice and other techniques in pre-Columbian Mesoamerica is demonstrated by the cranial remains in pre-Columbian burials, iconographic artworks, and post-colonial reports. The intellectual understanding of neurosurgery developed during the golden age of ancient Greece where no surgeon restricted oneself in strict to neurosurgery. Head injuries on the other hand appear to have been abundant; an expected result of wars and internecine conflict, as recorded by Herodotus, Thucydides, and Homer. Then and now, war remains the primary source of study material for the improvement of knowledge regarding head injuries. Surgical procedures for the management of even minimal lesions of the theca cranica, continued throughout the 16 th and 17 th Century. The surgical technique, with cross-shaped skin incision and the instruments used (trephine, lever, scalpel, gouge, protector of the meninx, etc.) would remain unchanged with respect to the past, but one should take notice at the improved quality of the materials and the ameliorated precision with which the instruments were made. Some instruments appeared to be real work of art, as shown by the findings now displayed in museums and in illustrations of the times. The most ancient technique of craniotomy involved using abrasive instruments to thin down the bony wall. Subsequently, circular incisions were progressively made deeper, or a series of small holes were made in a circular fashion. The remaining bony bridges between these small holes would be broken down. The two latter methods that continued to be used for a very long period depended on using metal instruments.

Keywords: Traumatic Brain Injuries, Craniotomy, Tools of Craniotomy

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Introduction

The presence of head injuries predates recorded history as myths and old stories. In fact, drilled holes over fracture lines were observed over skulls retrieved from battleground graves.[1,2] These findings may be suggestive of trepanation usage for the treatment of trauma-related head injuries (TBI) during these times. Ancient Mesopotamians were aware of the complications that usually accompanied TBI such as seizures, paralysis, loss of visual, auditory functions or speech defects.[1] The Edwin Smith Papyrus (1650–1550 BC), describes head injuries with their symptoms and further classifies the injuries based on their presentation and tractability.[2] Physicians of ancient Greece (including Hippocrates) showed understanding of the brain being the center of thought. This understating may be related to their experience with TBI.[3] Surgeons during the medieval ages and later during the Renaissance continued the practice of trepanation as management of traumatic head injuries.[3] In the Middle Ages, physicians further described TBI symptoms, and the use of the term "concussion" became more common.[4] Berengario da Carpi was the first to systematically describe in the 16th century the symptoms related to concussion.[3] It was first hypothesized during the 1700s that TBI-related symptoms were due to an increase in the intracranial pressure (ICP) rather than being due to direct skull damage. During the 1800s, this hypothesis was confirmed when it was proposed to open the skull as a therapeutic attempt to decrease the intracranial pressure. Technological advancement of the 20 th century allowed for drastic improvement in the treatment and diagnosis of TBI. Imaging tools such as computerized tomography (CT) and magnetic resonance imaging (MRI), and, in the 21st century, diffusion tensor imaging (DTI) became more readily available and more reliable. Furthermore, ICP monitoring

was introduced in the mid-20th century and the modern era of head injury has begun.[5,6] Up until the 1900s, TBI was associated with high mortality rate and rehabilitation was not common. Significant improvements in care made during the first World War decreased the death rate and rehabilitation became relatively more common.

Subjects and Methods

As a matter of fact, facilities specialized in rehabilitation were first established during World War I. Additionally, there was a large number of TBIs related blast injuries during this war period, which allowed researchers to learn and further develop their understanding regarding localization of brain functions. Blast-related injuries are now common pathological entities seen in veterans returning from war in Iraq and Afghanistan. The literature asserts that the symptoms of TBIs are largely similar in both blast related injuries and physical blow to the head. In the 1970s, TBI became a public health matter,[7] and significant progress was made in research involving brain trauma,[6] such as the discovery of primary and secondary brain injury. In the 1990s, standardized guidelines were developed and established for the management of TBI. They included protocols regarding the pharmaceutical therapy and the management of increased ICP. Since then, research has improved TBI survival. That decade was known as the Decade of the Brain for the advances that were made in brain related research.[8] In Prehistoric period: As one might expect, prehistoric surgery lacked knowledge of the anatomy, concept recognition of the disease, and comprehension of the disease's origin. Unfortunately, failure to deeply understand these important principles delayed the progression of medical and surgical practice. Trepanation may be one of the oldest surgical interventions for which archaeological evidence is present.[9] Furthermore, trepanation may have been widespread in some areas. Many surgeries around the world display an example of skull trephination, which is an example of the early surgical procedures in neurosurgery. Many arguments have been made to explain the rationale behind this early operation or its origin; however, no satisfactory answers were provided to this day. Religion reasons, correction of head injuries, demon exorcism, headache management, etc. has all been offered. Unfortunately, no archaeological evidence was presented to provide a satisfactory answer. Nonetheless, one must admire the surgical skills of these early surgeons. Around 120 skulls were found at burial site in France and they dated to 6500 BC. It was found that 40 of the discovered skulls had trepanation holes.[10] Furthermore, researchers noticed that many skulls of the prehistoric and premodern eras had structure healing, which may indicate that many of the patients that underwent the surgery survived.In Pre-Columbian Mesoamerica : Evidence of trepanation practice and other techniques in pre-Columbian Mesoamerica is demonstrated by the cranial remains in pre-Columbian burials, iconographic artworks, and post-colonial reports. Among societies of the newer era, trepanning was most commonly found in the Andean civilizations such as the preIncan cultures like the Paracas culture Ica (South of Lima). It was found in the Muisca Confederation,[11] (modern day Colombia) and the Inca Empire where even cranioplasty was present. It was much less common among the Mesoamerican civilizations, at least based on the few uncovered trepanated crania.[12] Archaeological records from Mesoamerica further complicated the evidence of trepanation use due to the common practice of postmortem skull mutilation and modification to fashion trophy skulls, especially skulls of the captives and enemies. The aforementioned tradition was illustrated in pre-Columbian art which depicts rulers with the mutilated skulls of their defeated enemies, or of the sacrificed victims during rituals. Many cultures of Mesoamerica used to impale the skulls on wooden stakes (known by its Nahuatl term, tzompantli). Fortunately, some evidence of genuine trepanation in Mesoamerica has survived. The earliest archaeological record regarding crania trepanation was carried by Carl Lumholtz during the late 1900s involving specimens recovered from the Tarahumara mountains.[12,13] Later research documented cases identified from Tilantongo, Oaxaca and the major Zapotec site of Monte Albán. Two specimens recovered from the homeland of the Tlatilco civilization date back to around 1400 BC and indicate that the practice has a lengthy tradition.[14] This is evidenced by the usage of several techniques and the fact that some individuals received more than one trepanation, suggesting that it had been done for experimental reasons. The study came to the interpretation that trepanation usage as an indicator of the stressful sociopolitical climate later on resulted in the abandonment of Monte Alban as the primary regional administrative center in the Oaxacan highlands. While comparing specimens retrieved from the Maya civilization in the regions of southern Mexico, Guatemala, and the Yucatán Peninsula to those found in central and highland Mexico, there was no evidence of the drilling or cutting techniques. It seems that the pre-Columbian Maya civilization used an abrasive technique that ground away at the back of the skull making the bone thin with resultant perforation, similar to the examples from Cholula. Many skulls retrieved from the Maya region date from the Postclassic period (ca. 950–1400), and include specimens found at Palenque in Chiapas, and recovered from the Sacred Cenote at the prominent Postclassic site of Chichen Itza in northern Yucatán.[15] In Pre-modern Europe Trepanation was noted to be practiced during the Classical period and Renaissance period. Hippocrates, the Greek physician considered the father of medicine, provided specific directions in order to perform the procedure from its evolution through the Greek age, Galen also elaborates on the procedure. During the Middle Ages and the Renaissance, patients with seizure and patients subjected to skull fractures underwent trepanation as a cure for their ailments. Researchers retrieved eight skulls with trepanations from Southwestern Germany dating back between the 6th to 8th century; among the eight skulls, the researchers noted that seven skulls had clear evidence of post-trepanation healing and survival. These findings are suggestive of a high "post-

operative" survival rate and low infection-related complications.[16] Archeologists retrieved skulls from the graveyards of pre-Christian (Pagan) Magyars and came across surprising findings where 12.5% of the skulls were skulls with trepanation. The procedure was performed on adults only, with equal distribution between males and females, but with increasing frequency with age and wealth. This practice disappeared with the beginning of the Christian era.[17,18,19,20]

Results

In Medieval Europe: Constantinus Africanus (1020 – 1087) introduced Arabic medicine to the school of Salerno and consequently to Europe. He studied in Baghdad, where he came under the influence of the Arabist. Later, he would retire to the monastery at Monte Cassino where he would spend his time translating Arabic manuscripts into Latin, albeit rather inaccurately. Roger of Salerno (fl. 1170) was a surgical leader in the Salernitan tradition and the first to write on surgery in Italy which would later have a marvelous influence on the medieval time. His Practica chirurgiae described some interesting surgical techniques.[21] Roger introduced an unusual technique to check for a dura tear or for cerebrospinal fluid (CSF) leak in a patient that sustained a skull fracture.Guy de Chaulaic (1298 – 1368) was the most influential surgeon during the 1300s and 1400s. He discussed head injuries in his Ars chirurgica. It reflected his knowledge and intellect. He proposed shaving the head prior to incision in order to prevent hair from entering the wound and negatively affecting primary wound healing. He advocated for the use of wine in depressed skull fractures to assist healing and to act as an early form of antisepsis. He classified head wounds into seven types from those that require only cleaning and debridement to those that require trephination and elevation such as compound depressed skull fracture.He also advised repair by primary suture and claimed to obtain satisfactory results. In order to provide adequate hemostasis, which is rather a difficult problem in the surgical field, he used egg albumin. By the end of the 19th Century, researchers with particular interest in this field came to acknowledge that the holes in the skulls were not due to accidental traumas; but rather they were perforations made by instruments for well-defined purposes. Doubts were expressed concerning the possible meaning of these holes and in the techniques and types of instruments used in making the perforations. Following those aforementioned findings, from the end of the 19th Century onwards, a marvelous number of skulls with signs of craniotomy were found throughout the corners of the world, especially the countries bordering on the Mediterranean, Central and Eastern European countries, Scandinavia. Interestingly, all these areas showed evidence of Neolithic settlements, while several more, belonging to a later period, were discovered in what is now central America (Mexico and Peru).[22,23,24,25,26] The most popular theory claims that the very first craniotomies were probably performed during the prehistoric era for reasons related to magic or religion, or may be related to an initiation practice, as hypothesized by Broca.[24] It may have been performed as an exorcism method to get rid of demons/malignant spirits infesting the human brain. It seems that skull drilling accounted for religious importance, since from some of these skulls, diskettes of bony tissue were removed post mortem, which were later then worn as amulets around the neck (the so-called "rondelles", described for the first time, by Prunières, in 1783).[24,26] As time progressed, the primary use of craniotomy was for therapeutic purposes. The encephalic decompression accounted for clinical improvement in certain pre-existing neurological symptoms, such as headache, paresis, and convulsive states. This led craniotomy to being performed in patients presenting with these symptoms and, in particular, patients with TBI. These symptoms would soon become the indication for skull drilling which in turn allowed the removal of embedded fragments, bone fragments and clots, and led to results quo ad vitam that were spectacular for the prehistoric culture. Around half of the patients survived the surgery, some of them for years to come, as depicted by the finding of signs of regenerated bone in many of the skulls. This occurred despite the procedure holding high risks of complications such as hemorrhage or infection. The medical Neolithic men had reached remarkable technical skills in performing this type of surgery despite the primitive tools such as pointed or sharp cutting tools derived from silica or obsidian (23, 26) . Following the pre-historic and classic Graeco- Roman eras in which craniotomy was a common practice, it would be performed only in some specific circumstances by the Byzantine, Arab and Eastern surgeons, throughout the Middle Ages. There was a tendency to limit performing trephining, and to preferring treating the patient medically as far as the condition would allow. An example is provided in the Volume on surgery by Lanfranco da Milano, at the end of the 13 th Century ("... multo plures curantur medicinarum modis quam perforantium trepanorum").[22] All the main authors of that time agreed with the rationale behind this approach and only a few were against such as Jan Yperman, the father of Flemish surgery. Furthermore, Guy de Chauliac would go as far as to propose the procedure to Pope Clemente VI, as a therapeutic approach for his severe, unrelenting headache.[23] The mediaeval authors' argument was that the brain is to be protected from air "(considered to be extremely harmful) with. "Nihil est quod ita immediate laedat cerebrum sicut aer" pointed out, in this respect, by Guglielmo da Saliceto, in the second half of the 1200s.[26] Few data exist on that matter, but all these authors were convinced of the need to place a hermetic barrier between the external surroundings and the exposed parts of the brain, resulting from traumas or surgical procedures. After a significant period of decline, the Renaissance was marked by the use of surgeries involving craniotomy on a wide scale. This is due to the widespread use of firearms which greatly increased the incidence of skull trauma and associated fractures. The indications, the surgical technique and the required instruments are described with great detail in the most important volumes dedicated to surgery in the 16 th Century. They allow one to gain an extended understanding of the state of the art as far as concerning skull trephining during the 16 th Century. This appreciation comes not only through the texts, but mainly

through the marvelous illustrations in three fundamental works of that period, namely: "Tractatus de fractura calvae sive cranei" by Giacomo Berengari from Carpi,[27] "Dix livres de la chirurgie" by Ambroise Paré,[28] and "Cirugia universale" by Giovanni Andrea Dalla Croce.[29] In the 16th Century, surgeons would attempt at first to remove the bone fragments and the clots in patients with severe skull fractures. The surgeons also operated for brain decompression and drainage of accumulated blood and/or purulent material which may have resulted from the traumatic event of from other pathologies that infectious or vascular in etiology. It is important to point out that Paré advised trephining as a therapeutic approach of post-otitic meningo-encephalitis, which resulted in the death of François II of Valois. This procedure was not performed due to the Privy Council's opposition. Angulated manual trephines, equipped with a series of perforating or cutting terminals, were employed when the surgery was performed. Surgical procedures for the management of even minimal lesions of the theca cranica, continued throughout the 16th and 17th Century. The surgical technique, with cross-shaped skin incision and the instruments used (trephine, lever, scalpel, gouge, protector of the meninx, etc.) would remain unchanged with respect to the past, but one should take notice at the improved quality of the materials and the ameliorated precision with which the instruments were made. Some instruments appeared to be real work of art, as shown by the findings now displayed in museums and in illustrations of the times.[30,31] Furthermore, during the second half of the 1600s, Vieussens, Malpighi and Willis improved the understanding of the neurophysiological aspects with their studies. They stress on the important role of the cerebral cortex, that had not been understood during the previous times, as well as on the role of the humoral theory taking into consideration only the ventricles as the important structures of the brain.[32,33,34] There was a noticeable decrease in performing craniotomies from the end of the 18th Century and onwards due to the increased incidence of infection-related complications. Infections in hospital settings such as wound suppuration became so frequent that the famous surgeon, Sir James Simpson, proclaimed that a hospitalized patient risked more than a soldier on the battleground.[35] Trephining was subsequently limited to specific cases and instead, decongestive medical treatment was favored, albeit it lacked efficiency.[23]

Discussion

Traumatic Brain Injuries in the Ancient Egypt TBI is probably as old as the dawn of humans. The Edwin Smith Papyrus was the first to describing the management of patients with TBI. This gave insight to the medical examination and treatment of patients with head injuries in ancient Egypt. Several cases are of significant importance to the field of neuroscience since they contain discussions regarding the brain, meninges, spinal cord, and cerebrospinal fluid for the first time in recorded history. Additionally, the papyrus is the first to describe the brain, pulsations, contusions as resulting complications of TBI, the dura, and cerebrospinal fluid, which reveals, to a certain extent, sophisticated knowledge of cerebral anatomy. Furthermore, ancient physicians examined wounds, signs of basal skull fractures, with the associated complications such as neurological or infectious manifestations and classified the injury pattern according to their prognosis. Ancient physicians suffered from limited therapeutic options at that time. However, the Edwin Smith Papyrus shows the remarkable observational skills of the ancient physicians given the methods and limits of that time. These physicians recognized several symptoms associated with TBI and assigned them a prognostic value.

Traumatic brain injuries in the ancient Greek: The intellectual understanding of neurosurgery developed during the golden age of ancient Greece where no surgeon restricted oneself in stricto to neurosurgery. Head injuries on the other hand appear to have been abundant; an expected result of wars and internecine conflict, as recorded by Herodotus, Thucydides, and Homer. Then and now, war remains the primary source of study material for the improvement of knowledge regarding head injuries. The earliest medical writings from this period are generally thought to be the writings of Hippocrates (460- 370 BC), the most celebrated of the Asclepaidae.[17] Hippocrates was the first to describe several neurologic conditions associated with injuries sustained on the battlefield. He showed an understanding of the importance of injury location and categorized the brain's vulnerability to injury from lesser to greater based on location. An injury to the bregma was associated with a greater risk than an injury sustained to the temporal region, which in turn carried more danger than injury to the occipital region (18) . He also described the use of the trephine and advocated the use of trephination in brain contusions but not in depressed fractures of the skull since it carried a grave prognosis. Furthermore, he cautioned that trephination should never be performed over the suture lines of the skull since there is an increased risk of underlying dura. Hippocrates would also recommend watering the trephine bit well to prevent overheating and subsequent injury to the dura. In the section on Wounds of the head, he argued against incising the brain since convulsions may develop on the opposite side. He also warned against skin incision over the temporal artery in order to prevent the occurrence of contralateral convulsions and severe hemorrhage. Hippocrates showed understanding of the simple concepts of cerebral localization and appreciation of the serious prognosis in head injury. Hippocrates maintained that there should be no delay performing the craniotomy and that it should be preferably done within the first three days of a severe contusion or a simple fracture. He also suggested in the case of the comminute type or with embedded fragments, that they be removed while paying particular attention to preserve the meninx. When a craniotomy was to be performed, the crown drill ("trupanon") and perforating drill were employed. Hippocrates mentioned these instruments without describing them which reflect that they were in common use during those times. Aulus Cornelius Celsus (25 BC-AD 50) is a medical encyclopedist in the field of neurosurgery who made a number of interesting

observations. De re medicina contains an early description of an epidural hematoma due to a bleed from the middle meningeal artery.[17] He recommended that surgeons should always operate on the side where pain is greatest and place the trephine where the pain is localized best. Considering the innervation of the dura and its sensitivity to pressure, the aforementioned statement has proven to be a good clinical suggestion. Celsus also clearly described the craniotomy technique and the instruments required to perform it: he claimed that osteotomy should be done progressively, involving first the external cortex, then the diploic tissue and, last of all, the internal cortex. Attention should be paid to the meninx, where he advised the use of "meningophylas" to protect it, and a slightly angulated bronze lamina, to be inserted under the bone planned to be removed in order to protect the encephalon. Tapping opened the bone with a small hammer ("malleus"), on a sharp "scalper", by means of the small perforating trephine ("modiolus"), or with a large crown trephine ("terebrum"). Galen of Pergamus (Claudius Galenus, AD 129200), Galen was much more liberal than Hippocrates when it came to head injuries. He made the argument of elevating depressed skull fractures, fractures with hematomas, and comminuted fractures. Galen would also go on to recommend the removal of bone fragments, particularly those pressing into the brain. Galen was also more optimistic. He extensively described the safe use of the trephine, while maintaining that the dura should not be violated. Paul of Aegina's (AD 625 – 690) classic work, The Seven Books of Paul of Aegina, contains a remarkable section on head injury and the use of the trephine.[19] He categorized the fractures of the skull into fissure, incision, expression, depression, arched fracture, and, in infants, dent. In fracture management, he described an interesting skin incision where two incisions intersect one another at right angles, giving the Greek letter X, with one leg of the incision incorporating the scalp wound. Patients would have their ears stuffed with wool to cancel the noise coming from the trephine in an attempt to prevent distress. Wound dressing would be later achieved with a broad bandage soaked in rose oil and wine, with subsequent care taken to avoid compressing the brain.[20,21]

Conclusion

The notions of asepsis, antisepsis, and general anesthetics were introduced in the second half of the 1800s which led to a marked progress in surgical field, and thus, trephining began to be used again to a certain extent. The major goals of anesthetic management of TBI are tomaintain CPP; treat increased ICP; provide optimal surgical conditions; avoid secondary insults such as hypoxemia, hyper and hypocarbia, hypo and hyperglycemia; and provide adequate analgesia and amnesia. Important pharmacodynamic and pharmacokinetic differences exist between intravenous and volatile anesthetic agents. Intravenous agents including thiopental, propofol and etomidate cause cerebral vasoconstriction and reduce CBF, CBV, cerebral metabolic rate of oxygen (CMRO2) and ICP.[36] Opioids have no direct effects on cerebral hemodynamics in the presence of controlled ventilation.[37] All volatile anesthetic agents (isoflurane, sevoflurane, desflurane) decrease CMRO2 and may cause cerebral vasodilation, resulting in increasing CBF and ICP. But at concentration less than 1 minimum alveolar concentration (MAC), the cerebral vasodilatory effects are minimal and hence they may be used in low concentrations in patients with TBI.[38] Nitrous oxide can increase CMRO2 and cause cerebral vasodialation and increased ICP and should be avoided.[39] Importantly, the effects of anesthetic agents (inhalation vs. total intravenous anesthesia) on outcome of TBI have not been demonstrated. In the absence of conclusive evidence, either anesthetic technique may be employed judiciously. However, more importantly, the principles of anesthetic management should adhere to the current guidelines for the management of severe TBI. The use of trephining was halted as a first line treatment of skull traumas since a better understanding of the neurological aspects developed. Consequently, craniotomies began to be performed to treat extensive encephalic lesions. It would be much later when metallic instruments such as gouges, curettes, scalpels, knives were made of copper or bronze. Some of these instruments were very special, such as the "tumi", or scalpel, in ancient Perù.[25] It is worthwhile to take a closer look at the drill that is one of the oldest instruments known. Originally, the drill may have been a consequence of a technique used by early man to create fire. These men would use the palm of their hands to rapidly rub a rod hammered into a piece of wood with an inflammable agent. If the used rod was made of hard material, then it would enlarge the pre-existing hole or even make a new one. This observation was responsible for the birth of the early drill. The early drill consisted of a small sharp rod made of stone or metal that would be rotated quickly between the hands. To achieve a greater speed, they passed a cord around it and its ends were pulled consecutively with a fast "to and from" movement. The early drill sustained further improvement when the strings of a bow were fixed to the perforating rod. This would allow this maneuver to be performed by a single person. The most ancient technique of craniotomy involved using abrasive instruments to thin down the bony wall. Subsequently, circular incisions were progressively made deeper, or a series of small holes were made in a circular fashion. The remaining bony bridges between these small holes would be broken down. The two latter methods that continued to be used for a very long period depended on using metal instruments.

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