American Journal of BioMedicine
AJBM 2015; **3**(7): 381- 409
Topic Review
doi:10.18081/2333-5106/015-07/381-409

History of Traumatic Brain Injury (TBI)

Gonzalo Bertullo [1*]

Abstract

History is of one of the many disciplines that is considered as science, and which allows past events to be studied. This allows us to know about past facts, accompany their evolution, the origin of many concepts and terms, as well as errors and myths, allowing a comprehensive understanding of the present and learning to improve the future. The importance of history is such that it ends up determining the culture of many countries and also frames scientific disciplines. The great advances in knowledge of neurological function and its brain localization began in the nineteenth century. It is only recently that head injuries are classified by their neurological deficit rather than the type of skull fracture. This is not surprising, since most head injuries were treated by general surgeons who knew little about neurological examination. Although the illustrations in the early sixteenth century showed the anisocoria, this condition was not mentioned until three centuries later, when Jonathan Hutchinson first reported a dilated pupil on the same side as an intracranial clot, and pointed out that it was due to the compression of the third cranial nerve.

Keywords: Trauma; Brain injury; History; Skull fracture; Neurological deficit

[*]Corresponding Author: Gonzalo Bertullo: gonzalobertullo@hotmail.com
[1]Department of Neurosurgery, College of Medicine, Clinics Hospital
Montevideo-Uruguay
Received March 02, 2015; accepted June 27, 2015; published July 24, 2015

Introduction

History is of one of the many disciplines that is considered as science, and which allows past events to be studied. This allows us to know about past facts, accompany their evolution, the origin of many concepts and terms, as well as errors and myths, allowing a comprehensive understanding of the present and learning to improve the future. The importance of history is such that it ends up determining the culture of many countries and also frames scientific disciplines.

In Medicine, and in particular, surgical discipline, these principles are

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paramount in importance and application, as expressed by the first medical document known in the history of Medicine: the Edwin Smith Papyrus, a real treatise of trauma. In this regard, in this chapter we will travel throughout the history of traumatic brain injury (TBI), its terms and evolution, following a timeline based on how the most significant historical events were developed.

Pre-historic and historical periods

If we draw a timeline following a traditional view, human evolution is divided into a period called Pre-History, which runs from human origin to the appearance of written documents, and another known as History, beginning with the appearance of written evidence and it marks the certainty of knowledge based on events determined by our ancestors [1]. Archeology, through the study of material remains, was the only resource to reconstruct facts before the appearance of scripts.

Pre-History has three main stages: Paleolithic, Neolithic and Metal Age. History is born with writing and includes four major stages: Ancient History, middle Ages, Modern Era and Contemporary History, each of them limited by major events (Fig.1) [1].

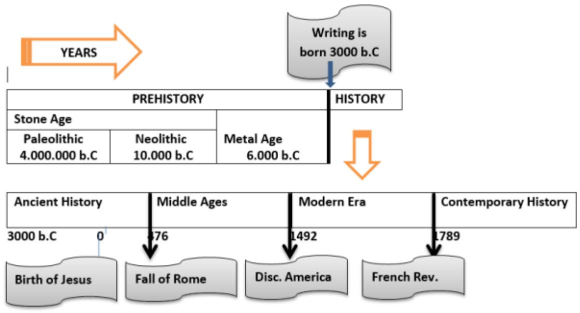

Figure 1.

Timeline of Universal History

TBI in pre-history

During the Paleolithic period, approximately 2.7 million years B. C., the ancestors of man (Homo Habilis, Australopitecus, Homo erectus) [1, 2] appear. The man accepted as such (Homo sapiens) would have appeared in the Middle Paleolithic period (100.000 years B. C), and consolidated in 40.000 B. C. Attacks on human brain skull over this period are mainly due to injuries caused by different animals, and not man.

In this pre-historic period, the first evidence of brain injury in human evolution appears (2.000.000-1.800.000 years B.C approximately). It was found in Olduvai Gorge, Tanzania, apparently due to a crocodile bite (1, 2). Subsequently, other injuries appear, like the one found in the ape-like man (Australopithecus Africanus) in South Africa. The Australian anatomist and anthropologist, Raymond Dart, argued

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that such injuries were caused by an antelope humeral condyles found in the immediate area and used as a tool to club its prey to death from behind [3]. Other anthropologists do not agree with this hypothesis and argue that these ancestors were not able to use "tools", and that the fractures found, were the result of attacks perpetrated by mammalian predators known as "cats or saber-toothed tigers" [4] (Fig. 2). Such fractures were found in later Hominids, Homo erectus, Java Man (300.000 B.C) and Neanderthals (40.000 B.C.) [1, 4].

Figure 2. Developed upper fangs like a curved sable.

In contrast, the earliest evidence of trepanation performed by man himself appears in the Neolithic period, and the interpretations of the earliest trepanations discovered have been diverse. Domenec Campillo in the Paleoanthropology Laboratory of Spain, who studied more than 3,000 ancient skulls during 14 years, emphasizes that it is unquestionable that trepanation began in the Neolithic period. Their reasons basically had to do with rituals and magic, and not for therapeutic purposes due to the results of the study regarding trepanations characteristics and the precarious knowledge at the time in all aspects [5]. It is believed that humans formed tribes giving origin to the "wizard" image and following the beliefs of the majority of primitive peoples; diseases were considered of divine origin and therefore the "wizard", who faced them, was a man with powers to communicate with the gods [1]. Trauma did not escape reality and apparently it was another reason for the need of "wizards" who probably were those who trepanned, even in living people according to anthropological results [1, 8, 27, 28].

BTI in ancient history

Ancient history is the historical period where ancient civilizations arise and develop, approximately 3,000 years B.C, and ends in 476 B.C with the fall of the Western Roman Empire. During this long period a large number of important events in history of BTI took place, which will be detailed in chronological order.

The Egyptian Period-Edwin Smith Papyrus

The origin of writing gives way to History, the period in which events that occur start to be documented, and hence, gives veracity to knowledge.

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The first written evidence of brain injuries is documented in Egypt in the Edwin Smith Papyrus, 3,000-2,500 years B.C. when the pyramids were built, being the first medical document recognized in the history of medicine [6,7] (Fig. 3).

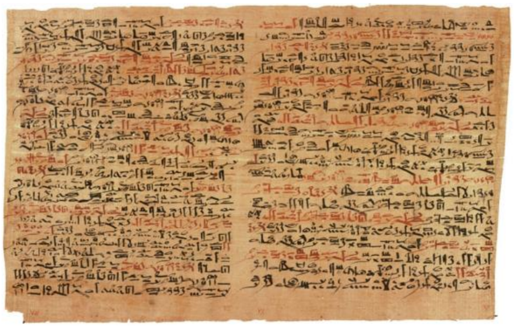

Figure 3.
Edwin Smith Papyrus

This is a real surgical trauma treatise, which reflects the high incidence of traumatic injuries of that time. It corresponds to a single scroll of 33cm high and 5m in length approximately, and assembled from multiple sheets of 40cm approximately It consists of 17 columns written on its front face and 5 on the back, all of them in horizontal lines (Fig.3). It describes 48 cases beginning with head injuries and moving down the body using a carefully prescribed formula: Title, Examination, Diagnosis, Treatment and definitions of terms used.

The procedure chosen in each case was carried out in three Diagnoses: a medical condition I can treat, a medical condition I can contend with, and a medical condition you wilI not be able to treat [6, 7, 8, 10]. There were 27 head injury cases of which 13 were fractures with neurological involvement and the rest only soft tissue injuries [6, 8, 10].

The fractures were classified as: 1) splits (fissures or linear fractures) 2) smashes (comminuted depressed fractures) 3) compound comminuted, 4) Conminuted and depressed [8, 10]. It is accepted that its author was the oldest Egyptian physician, Imhotep [6, 8, 10]. These data show the "state of medical art" in ancient times and its great capacity of systematization.

Observation and palpitation were transcendent and for first time the terms fracture, brain, meninges, convulsion, cerebrospinal fluid (CSF) and suture [6, 8, 10, 11] were introduced. Edwin Smith (1822-1906), an American Egyptologist, is the person who obtains the papyrus that now bears his name. This is because Smith was visionary about the hierarchy of the document, and the important task of following the seller to buy his parts, put it together, identify and accommodate its elements, and missing spaces. He kept it until his death and his daughter donated it to the Historical Society of New York [6, 8, 9, 10]. In

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1920, Breasted, Director of the Institute of Oriental Studies in Chicago, was asked to translate and edit the whole text which was published ten years later [9].

The Bible

Few are the biblical references regarding head trauma. Its origins are dated after the Edwin Smith papyrus between 1300 to 1000 years B.C., where initially injuries by crocodiles are mentioned in Psalms (74:13,4). All the injuries resulted in death without instance of recovery or reporting of treatment as expressed in Isaiah (1:6), Genesis (50:2), and Jeremiah (8:22). However, the Bible describes in detail three cranial injuries: Sisera's death at the hands of Jael; skull fractures on Abimelec; and the most famous death of Goliath by David [12, 13].

The story of Sisera and Jael, the latter being one of the strongest women in biblical history, is narrated in the book of judges in the Old Testament (4:21-22; 5:26). Sisera was the commander of the Jabin army, King of Canaan, whom Deborah and Barac defeated in a war fought by the river Kishon. He survived, fled the battlefield and sought temporary refuge in Heber's tent, a Ceneo that until that moment lived in peace with the Canaanites. Jael, Heber's wife, offers him a bed and milk. While he was sleeping exhausted by fatigue, she kills him instantly by hammering a stake in his "temple" till reaching the earth; the opponent of the Israelites was put to death at that very moment (Fig. 4).

Figure 4.
Sisera's death by a penetrating wound

The story of Abimelech is also described in the book of judges in the Old Testament (9:50-54) [12,13].

Abimelech, a "self-proclaimed" King, ruled Israel for three years, and conquered and killed the rebels from Shechem and its inhabitants, the first capital of the kingdom of Israel. Subsequently, he sought to approach the Tebes tower (now known as Tubas in the northeast of Cisjordania) as it was the refuge of the all the people from the town, and set it on fire. When approaching to the tower, a woman throws a millstone from the roof of the tower which impacts his skull, and eventually culminated in his death. During a moment of lucidity, he asks one of his squires to kill him with his sword to simulate that a brave man like himself was actually killed by a soldier and not by “a stone” thrown by a woman. Finally the most famous biblical story and fight between David and Goliath gives an account of another cranial injury (1st book of Samuel 17:49-51). Goliath was a leader of the Philistine soldiers from the city of Gath, who wore strong armor, a helmet and carried a sword, and was about 2.9 meters tall. For 40 days he defied the Israeli army in the Valley of Elah to choose a man who would fight against him and whoever lost would submit to slavery.

David was a young shepherd that arrives at the scene to deliver food. When he hears the challenge, he immediately offers to fight Goliath without armor, and only holding a sling and stones. The giant falls literally from a “sling shot” by the stone that enters the basal front region. Like Abimelech, Goliath does not die immediately, so David ensures his death by beheading Goliath with his own sword. Literature indicates some doubt regarding the ease with which a young Hebrew defeats a heavily armed giant with only a sling. This was difficult to accept, so a medical explanation was sought. The hypothesis accepted is that Goliath was a carrier of multiple endocrine neoplasia type 1 (pituitary, parathyroid and pancreas tumor) that ultimately caused his death indirectly [12, 14, 15, 16]. The macroadenoma determined acromegaly and visual field deficit, the latter allowing David to approach the giant unnoticed (biblical witnesses said Goliath had to look around to find David).

Osteitis fibrosa as a result of hyperparathyroidism is determined the Goliath’s skull thinning, contributing to the easy penetration of the stone in the skull, and a pancreatic tumor that secretes insulin or gastrin hormone (with subsequent of the hypoglycemia or hyperacidity) mean that morning was a bad time to fight [12, 14, 15, 16] (Fig. 5).

Figure 5.
David and Goliath

Homeric Period -XI-VIII B. C. Century

Homer was a Greek poet who was believed to have lived in VIII B.C.

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century. This period is also known as the Greek Middle Ages or dark Ages. The oldest source of Greek knowledge are Homer's poems: Iliad and Odyssey. The Iliad tells the story of Achilles during the Trojan War, and the Odyssey, the return of Ulysses to Ithaca after the War. In the Odyssey, Homer mentions injuries caused by skull indentation. In the Iliad, there is mention of penetrating wounds as a result of spears, swords, and arrows. He describes a higher rate of mortality due to wounds caused by spears and swords rather than arrows, and explains that in the latter, if vital structures are not injured it may heal without infection after removing the arrow [8].

In this same work Homer also describes the "explosion of two" of a Greek warrior during the siege of Troy when he was hit in the head by a rock. This data provides a "predictive" idea of the situation experienced in the period and the predominance of penetrating wounds in the skull as a cause of BTI. Both epics are the culmination of a long tradition of oral poetry that emerged between 1300 B.C - 1100 B.C and put into writing in VIII century B.C.

Hippocratic Period- V- IV B.C. Century

Hippocrates of Kos (460 B.C- 370 B.C) is one of the most outstanding figures in the history of medicine and considered by many as the "father of Medicine" [17, 18, 19]. He was born on the Greek island of Kos and his contributions to BTI were transcendental (Fig. 6).

He was the first physician to perform a systematic approach to BTI in his work: "On injuries of the head". It deeply analyzes the cranial anatomy and clinical observation that resulted in a variety of surgical procedures, each applicable to different types of skull fractures and brain injuries [8, 20]. Trepanation, but for therapeutic purposes, is widely specified with its clinical, technical indications and results. While Edwin Smith Papyrus classified fractures into linear and comminuted with or without depression, Hippocrates proposed a new classification of six categories [8, 20]:

1) Fissured fractures: he described that all possible varieties could exist, from non-visible to distinguishable fine fissure or extensive wide linear fractures; 2) Bone contusion: it corresponded to a bruised bone without fracture and stressed that it was not visible to human eye; 3) Depressed skull fractures: it is when an area of the bone is "depressed" and the rest remains normal; 4) "Haedrae"- dints or "marks" with or without fractures: he introduces

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the term referring to bone “mark” that defines the shape of the object that generated it; 5) Countercoup fracture: he also introduces this new concept of fracture in a different place where the trauma was received. That is, 25 centuries before an image could prove its existence, Hippocrates described it for the first time and said, “there is no possible way to examine … when this accident occurs, I cannot help” [8, 20]; 6) Fractures on cranial sutures: he highlighted this separately because he maintained that they represented a naturally weak spot, and thus, more easily damaged.

For the first time, Hippocrates introduces the importance of a detailed “record” of patient with BTI, something already inherent in the rest of the Hippocratic treatises. Through clinical observation he was also able to make an extensive and detailed description of the cranial anatomy as the dissection of the human body was not allowed in ancient Greece [20]. He describes the anatomy of the skull made of two layers and in the middle there is a “sponge” that contains "numerousa fleshy wet particles”, the diploe and a “membrane” that covered the brain, dura mater [20]. Treatment of fractures was an important chapter where first aids and bandages, wound exploration, and those fractures that required trepanation were included. He showed trepanation in a very interesting way in three types of fractures: fissured, bruised and haedrae. He did not recommend the depressed ones as he used the trauma itself and depression to remove it, yet he did recommend that fractures on the sutures should be done above them but adjacent to it if necessary [20].

Although there is no direct reference to the presence of dural sinuses just below the cranial sutures, their existence is clearly involved in this message. Hippocrates warned to avoid making a burr hole just above the cranial sutures, if this principle represents a deeper understanding of the underlying brain structures or an unpleasant personal experience, it remains a mystery. He could not help with Countercoup fractures, as he described.

Another interesting aspect is that he gave a three-day deadline for trepanation because otherwise the patient would die from suppuration [20]; this limit today is known to be the turning point from which chances of infection increase dramatically. It is assumed that he advised trepanation to provide an exit to pus rather than to evacuate blood clots that build up underneath. There is no

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mention of this, but perhaps it could be due to loss of information of the manuscripts. The ultimate goal was to trepanate and leave the wound open so the suppuration could flow out, and therefore, having more possibilities of a cure.

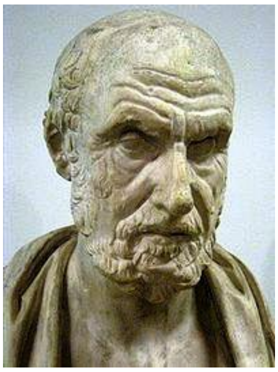

Figure 6.
Hippocrates of Kos

The Hippocratic concept that the formation of pus is a prerequisite for normal wound healing dominated the surgical practice until the Renaissance and is clearly represented in the Hippocratic aphorism, "You must make the wound fester as soon as possible " [20].

Four surgical instruments were used by Hippocrates: 1) a probe, that he use to examine the surface of fractures and to determine the depth of trepanation; 2) rasp, to “iron out” and find remains of bones in surface levels; 3) saw; 4) trephine. The latter was used to open the skull and produce a primitive bone flap, what is now known as craniectomy. Hippocrates apparently had trephines of different sizes especially for use in skulls of children [20]. Hippocrates changed the principles of superstition and magic by a medicine based on systematic observation. He encouraged and taught clinical evaluation of head injuries, proposed a new classification of skull fractures, applied therapeutic trepanation and presented prognostic factors. All these contributions combined with being the first treatise on medical history that deals with injuries exclusively on skulls, allow Hippocrates to be a pioneer of BTI according to some authors [20].

Trepanation

Human skull trepanation is the oldest documented surgical procedure performed by man. Trepanned skulls have been found from the Old World, (Europe, Asia and Africa) to the New World of America (especially the Incas in Peru), and from the Neolithic to the beginning of history [1, 5, 7, 20, 24, 26, 36, 37]. Trepanation methods were basically 4 types: 1) rectangular intersecting incisions; 2) boring and cutting (multiple small perforations); 3) grooving (creation of a circular…oval dent); and 4) scraping (oval curettage) (Fig.7) [8, 37, 38, 39]. The instruments used were originally made of sharp stones (Fig. 7). Over time they were refined to give way to the era of metals.

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The term trepanation derives from the Greek trypanon (bore or drill), a tool used to make a hole. Although it had been described in the Neolithic period, it was not therapeutic agent in everyday practice [21, 26, 36, 37]. The word trephina, however, comes from a later period and is of French origin, used to indicate the instrument ends in a sort of circular saw, which means that trephination involves the use of a cutting instrument with a trephina [21, 26, 36, 37].

Figure 7.
Kinds of trepanation and tools used

While both techniques determine a perforation of the skull as it involves the removal of a piece of bone with a tool, currently for these purposes, they are exchangeable term [21, 22, 36, 37]. Hieronymus Fabricius, an Italian anatomist and surgeon, is attributed with the description and invention of the trephine in his teatrises of surgery (Opéra chirurgica) in 1617, although it is accepted that it was already in use in the times of Christ [8, 23]. When the ancient Greeks performed a trepanation, they used a tool called terebra (rotating drill thatoperated by means of a belt around its center), or the trypanon that was handled by an arc (Fig.7b). A third tool, terebra serrata or modiolus serratus (any tool that makes a hole in the skull by rotation) consisted of a cone shaped metal, with a circular edge and with a lower toothed part, which was held in place by a central pin that could be rolled out quickly with the palm of the hand or a bow. The central pin is removed and the perforation is done. It is easy to understand that the terebra was the precursor of manual and electric craneotome trepanation used today for neurosurgical procedures [24] (Fig. 8).

Figure 8.
A tool similar to the terebra serrata. The pieces make it burr or trephine according to the distal end.

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Trepanation in the Old World

The trepanations found in Europe date back to 10.000 years B.C (Neolithic) and there are who mention that they date back as far as 350.000-100.000 years B.C (Paleolithic) [8]. The first skull was found in Cocherel- France in 1685 whose meaning was later recognized in 1865 when a second skull was found in the same place [29, 32]. Barthélemy Prunières, a French anthropologist, studied more than 200 skulls found in a prehistoric burial pit (Dolmen) in Lozère- France, and published it in 1868 under the title "Excavation of the Lozère Dolmen". It became the first publication on trepanation made by man [21, 32, 37, 40]. It is one of the largest and oldest collections of Old World and it is presumed it corresponds to Neolithic times of approximately 5000 years ago [21, 29, 32, 40, 41].

This collection was studied by Prunières immediately, who presumed some holes were made post-mortem, probably for making religious amulets and in other cases for therapeutic purposes. The size was very variable, from millimeters to real cranietomies with a maximum of approximately 13 x 10 cm, mostly parietal but also frontal and occipital. They were also found in other parts of Europe with similar characteristics, however, it is in the Museum of Anthropology in Paris where the vast majority of specimens are found (about 60) [21, 29, 31, 32]. Moreover, Paul Broca (1824-1880), a respected man in Europe for his knowledge and seriousness, and famous for his discoveries about language brain location (1861) and hemispheric dominance (1865), had founded the Society of Anthropology of Paris in 1859 and was considered as the world's leading anthropologist by many contemporaries. Broca had had contact for the first time, as we shall see later with trepanation in America, with a trepanned skull in Peru [40]. This fact had aroused Broca's interest in the study of trepanation in France, hitherto little known. With the strength and encouragement that characterized him, he began to study some skulls he found himself, but especially those found by other anthropologists and from his friend and partner Prunières [37, 38, 40].

Broca categorically concluded that most of the procedures were performed almost exclusively in children to treat benign childhood seizures. As a Neolothic man adjudged those "attacks" on evil spirits, trepanation was a simple way to "set them free". Since the isolated infantile convulsions were solved alone, practice culminated being a successful "surgical cure" and thus spread in successive generations [8, 28, 29, 38, 39, 40, 41]. Broca agrees with Prunières that most of the fragments removed, called "rondelles", were used as religious amulets, a little "biased" by the spiritual importance that reigned in France at the time [37, 38, 40]. Broca rejected the theory of trepanation by depressed fractures in France, as well as any other cause arguing lack of evidence in this regard. Nonetheless, many other authors discredited Broca's idea stating that Prunières collection did not have skulls of children and that they would have died immediately after carrying out the procedure [8, 37, 38, 40].

Twelve years after Broca's investigations, Victor Horsley (1857-1916), regarded by many as the "father of neurological surgery", studies the skulls found by Prunières and concludes that these trepanations were carried out due to post traumatic epilectic seizures by depressed fractures [8, 28,29, 38,39, 40, 41,42]. He was convinced that the procedure was carried out just where he believed the motor area was located [8, 37, 38, 40, 41, 42]. Regardless of the real dilemmas posed by major historical figures mentioned, the enormous contribution they made to the study of trepanation in Europe is clear, and these no doubt, were performed by various causes, whereby many of them were unknown. In Asia, trepanation was not universally popular and was performed due to insanity, epilepsy and headaches, so that the "demons could come out ."

In Africa, some people say that ancient Egyptians did not perform trepanation. Some evidence suggests that in fact there was, and a trepanned skull was found in Dynasty XII (2000-1788 B.C). [22, 29]. Towards the north of Africa trepanation was observed by Herodotus (484-425 B.C), and it also dates back to the Neolithic period, especially in the Tuaregs villages, as such skulls were found in the Canary Islands [22, 29].

Trepanations in the new world

In South America, the trepanned skulls dated from 5000 to 2000 B.C approximately. The first illustration of a trepanned skull was depicted by Samuel Morton (1779-1851) in 1839 in his anthropological atlas Crania Americana, but it was not recognized as such. The author believed it had been caused by the back of a battleax [29, 30, 32].

The first trepanned skull in a living person and recognized as a therapeutic case was found in 1865 by Ephraim Squier (1821-1888), an archaelogist, writer, and American diplomat sent to

Peru, who discovered a skull with a quadrangle left front bone defect of 15x17mm in a tomb in the Valley of Yucay [29, 31]. Squier considers it was important evidence that revealed the surgical knowledge South American tribes had. He presented the case at a meeting of the Academy of Medicine in New York the same year, and where it was recognized that the surgery and trepanation of the frontal had been performed on a living individual [29, 32]. Given the skepticism at the time, he took it to Paris to obtain a second opinion from Paul Broca, who presented the case in the Society of Anthropology and French Academy of Medicine in 1867. The skull was studied and signs of postoperatory inflammation was found which indicated an estimated survival of about seven days. Broca concluded that the procedure was carried out to "evacuate an epidural hematoma) "[29, 32].

From the 400 Peruvian skulls studied by JulioTello (1880-1947), a Peruvian doctor and archaeologist (currently in the Museum of the School of Medicine from Harvard), 250 showed elements of healing and regeneration at the edges of the holes; findings that indicate the survival of many people [33, 34, 35, 37, 38, 40]. Tello confirmed the surgeries were performed as treatment for depressed fractures that generated epilepsy as well as subdural hematomas [34].

Figure 9.
A Tumi

It is estimated that more than 5% of trepanned skulls were found in Machu Pichu, the multiple defects were of 3 to 5 with predominance of covexity and never encompassed sutures. They were carried out with a metal tool made of gold, bronze, silver, or copper known as Tumi, according to the Age of Metals [29, 31, 32] (Fig. 9).

Greco-Roman Period: V B.C – II A.C Century

In this period, the growth of Greek and Roman civilizations in Ancient History is developed. However, with Hippocrates' death in 370 B.C, the rise of Greek medicine begins to fall in contrast to the events occurring in other civilizations. From then and until the appearance of Galen of Pergamon (129-210 A.C), the school of Alexandria began to grow. The museum of Alexandria is created, where most of the information is collected and translated, leading science for over 300 years. Alexandrian physicians relied almost

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exclusively on the legacy of Hippocrates.

Aulus Cornelius Celsus appears on the scene (25 B.C-50 A.C), who is considered a physician for some historians, while others deny this condiction and consider him a very observant scientist who compiled information regarding medicine in Alexandria. In one way or another he stood out for collecting and recording in his treatise “De Re Medicina”, the medical knowledge of the time. He decribes the symptoms and signs to be taken into account when a person suffers a BTI, unconsciousness, vomiting, bleeding from nose or ears, if he/she communicates, motor condition, that is, Celsus makes a breakthrough in the basic assessment that today constitutes the Glasgow Coma Scale, and in the suspicion of fractures of the skull base. Celsus noted that serious head injuries could increase intracranial pressure (ICP) and argued that most severe brain injuries associated brainstem lesions [8, 26, 29, 33, 34, 35, 37]. In his treatise the extradural hematoma due to rupture of the middle meningeal artery and the diagnotic elements of a wound inflammation are described for the first time (heat, redness, pain, and edema) [8, 28, 29, 33, 34]. From the Hippocratic period it is recognized that lesions of the left side of the head caused convulsions on the right side and vice versa. Respecting this principle, during the Greco-Roman period motor paralysis and seizures determined, very often, contralateral exploration of BTI. Nevertheless, Celsus did not believe in Countercoup fractures as Hippocrates stated, and also unlike him, Celsus advocated the realization of holes to lift depressed fractures.

As the Roman Empire grew and influenced Greece, physicians divided and formed different groups that replaced the Hippocratic legacy by more philosophical than scientific theories. The School of Alexandria greatly contributed to knowledge of cranial injuries and established a “nexus” to the continuation of knowledge with the following figure: Galen of Pergamon . Galen of Pergamon (129-210 A.C) was the first to strongly refute the Hippocratic concepts founded on his great contributions to the anatomical and physiological studies.

As a physician of gladiators and keen observer in the Roman Coliseum, he could see and treat all kind of traumas and wounds, but wrote little about traumatic brain injury. These observations stand out in his work

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"Omnia Opera", where he describes his own classification of depressed fractures and the importance of not damaging the dura mater during surgery [29, 33, 35]. In contrast with Hippocrates, he proposed to always rule out comminuted fractures and supported Celsus in making holes to lift depressed fractures. He provided a detailed description of the different techniques of trepanation and insisted on the importance of brain protection during the procedure; he invented a kind of "dural protector (a flat piece of metal)" to lift depressed fractures and not injure the brain [8, 28, 29, 33, 34]. Galen is recognized as the first to introduce the term "autopsy" and differenciate dura mater from pia mater [8, 29]. After Galen, Paulus Aeginata followed (625-690), a Byzantine Greek physician, who moved to Rome and continued compiling and putting into writing the knowledge of the time in seven volumes. In the sixth volume, he talks about surgery and describes a drill for trepanation for the first time called abaptista which stopped automatically on impact with bone "protuberance". The same was associated to another piece called meningophilax which protected the dura mater. Aeginata describes fractures and their treatment, and like Celsus, he rejects the existence of countercoup fractures, and warns of the danger when removing an arrow that penetrated the brain [28, 29, 33, 35, 8]

BTI in the middle ages

Most historians agree that the Middle Ages begins with the fall of the Western Roman Empire in 476 and ends with the discovery of the new world in 1492. After the fall of the Roman Empire an intellectual "stagnation" followed in Greece and Rome, and the leaders recognized the Arabs to preserve this medical knowledge, thus, giving way to the Arabic Medicine period [8, 26, 28, 29, 33, 35]. This fact, along with the invasion of Europe by the Barbarians and the spread of Christianity, led medicine to be concentrated in the monasteries; monks became "healers" and performed medical procedures.

Arabic Medicine Period -VIII-X Century

Arab medicine placed the physician as an illustrious figure that did not allow contradiction and considered surgery as a despised and secondary discipline, hence, avoiding it. Knowledge of Hippocrates and Galen was used by most physicians in that period. The most prominent characters of Arab medicine were: Rhazés, Avisena and Albucasis.

Rhazés (852-932) was a physician that lived in Baghdad, and his fundamental contribution to BTI was to introduce, for

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the first time, the term concussion [8, 29, 33, 34]. Avicenna (979-1037) was born in Afsana, in present-day Uzbekistan, and wrote one of the most famous Medical Encyclopaedias known as Avicenna's Canon of Medicine, in 14 volumes by the year 1020. He translated the works of Hippocrates and Galen and introduced the treatment of epilepsy with medicinal plants among the most important contributions linked to BTI [8, 29, 33, 34].

Albucasis (936-1013) was born in Al-Zahra and was the main reconciler of Arab medicine with surgery as a discipline. His book "Altacrif" is based on the writings of Paulus Aeginata, essentially, a surgical treatise where Albucasis makes classifications of cranial fractures, surgical instruments and techniques of the time. Salerno's Medical School Period- X-XIII Century The church, which maintained the "monopoly" of medicine through monks who practiced it, demanded that the religious people of the time shave to be differentiated from others. Many of them moved to convents and began to learn the discipline taught by monks and to practice it. As a result, the figure of "barbers-surgeons" appears. In the middle ages, a dispute began between the barber-surgeon, "uneducated, without preparation, but affordable", and the surgeon, "skilled but expensive" (Fig. 10).

Figure 10.
A barber performing a craniotomy to "relieve headache".

The return of medical knowledge to Europe was by means of Constantine the African (1015-1087), a monk born in Carthage (city that was under Arab rule), who given his command of Latin could translate the Arab writings. The greatest source of knowledge in Europe between the X-XII centuries, was the Salerno's Medical School. It was the first medieval medical school located in Salerno, Italy. Constantine was invited to work at the Medical School by Alfano I (a monk who practiced medicine). Thus, he helped to reintroduce the classical Greek medicine into Europe. Hippocrates and Galen's translations were the first to spread the Greek knowledge of medicine to the west. He also wrote "Arab

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manuals" for travelers. Roger of Salerno, better known as Rogerius, was one of the leading surgeons of Salerno´s Medical School and who wrote the first medieval text, a real treatise on surgery that dominated the field throughout Europe and was influential until the modern times (Fig. 11**)**.

Figure 11.
Roger of Salerno removing an arrow.

His work "Practica chirurgiae" (The Practice of Surgery), had a therapeutic recommendation for each disease. Among his recommendations was the use of egg shell for wounds, gave an account of the maneuver of pushing for diagnosis of CSF leak, and used wool and feathers for hemostasis [26, 28, 29]. He postulated that traumatized nerves do not regenerate but still had to be anastomosed. The works of Roger of Salerno on skull traumatic surgery were important and considering he wrote his recommendations 800 years ago, they are surprisingly modern. In the skull: "if the wound is small, it should be extended unless the bleeding or other complication prevents it. The trephine should be used cautiously on each side of the fracture and make the necessary perforations. Then with a chisel a cut is made from one hole to another, so that the opening extends from end to end of the fracture and the exudation can exit. Later, it must be cleaned gently with linen strips placed by a feather between the brain and skull. After introducing a linen folding between the bone and the dura mater, the injured bone must be removed [8, 29].

In 1130, the Council of Clermot, and in 1163 the Council of Tours prohibit monks and religious people to practice any kind of Medicine, and especially surgery to avoid "blaming" a religious person of death. In 1215, this is ratified by Pope Innocent III, and, therefore, surgery is placed in the hands of barber-surgeons and not of physicians, given the Arab teachings and their contempt for surgery had been successful [33, 38].

XIII-XV Century

Salerno's tradition in the medieval period was continued by Brunus Longoburgi (Bruno of Calabria), Ugo Borgognoni and Teodorico Borgognoni (Teodoro de Cervia). Bruno argued that penetrating injuries of the pia mater were dangerous but those that entered in

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the ventricles were fatal. In Bologna, he made important progress showing his surgical techniques both to undergraduate and graduate students, and he completed a study on surgery in Verona in 1275. William of Saliceto (1210-1277), a barber-surgeon, could recognized a skull fracture by "the dull sound made by an extended thread between the little finger of the barber-surgeon, and the patient's teeth". Another associate to Salerno's Medical School was Walter de Agilon, a Frenchman who also emphasized the importance of applying clean linen bandages to the meninges.

In the late XIII century, Lanfranco of Milan (also known as Lanfrancus or Guido Lanfranchi) was the first to describe the concept of concussion as a brain lesion without fracture. He used a scalpel instead of a cautery. He developed techniques to differentiate himself from barbers [26, 28, 29]. His hypothesis was that symptoms followed by TBI could disappear quickly and this temporary paralysis of brain function was a consequence of brain "agitation". He proposed an only indication of trepanation, "dural irritation by depressed bone fragment ", and conceptualized that if fever and convulsions appeared together, prognosis was dark and gloomy. Nonetheless, if only one appeared, the prognosis was better. He realized that the loss of brain substance was compatible with survival and reported about two soldiers who lost brain substance from their frontal lobes and had good recovery but poor memory [8, 26, 28, 29].

The terms "hemisphere" and "lobes" were introduced by Willis in 1561, but the four main lobes were not named until 1807 by Chaussier. Willis was the first to consider the existence of the cerebral cortex and its importance in motor function and also to think in the existence of a blood – brain barrier. Already in the early XIV century, trepanation was continued by Guy de Chauliac (1300-1368) another great surgeon of that time and one of the first to shave patients for brain surgery, and one of the first in successfully removing part of the brain and clean. He recommended removing "bridles" by trepanation, but only with serious fractures and avoiding sutures [8, 26, 28, 29]. As we can see, the medical writings on BTI at that time came from Europe. In France, after the Council of Tours, surgeons who had studied at University formed one of the first medical societies in 1268. They were known as "Master

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Surgeons" and were more important than barber-surgeons, but less than physicians. They were known as the long-robe surgeons, which differentiated them from the barbers who wore short robes [28, 33]. In 1540, Henry VIII, King of England, separated the role of barber and surgeon, whereby the barber was in charge of his specific duty, and the surgeon operated; each one had to fulfill his own role. The same was applied in France and in 1743 Louis XV decreed the definite separation. The same occurred in England two years later, in 1745 [33, 28, 1].

BTI in the modern era

The beginning of the Modern Era is marked by various historical events, like the consolidation of European states, the discovery of America, among others, but, in turn, its development coincides with the Renaissance. This era began in the XV and XVI century that marks a cultural movement determining the growth of science and culminating in the late eighteenth century with the beginning of the Contemporary History. This period is received with various contributions to BTI with important and renowned personalities who advanced on the subject. Berengario da Carpi (1465-1527) (Fig. 12) was the noted referent of the sixteenth century, who was born in Carpi, was the son of a barber - surgeon, and had medical and engineering knowledge that enabled him to exploit the design of new instruments, drawing and writing [23, 43, 44].

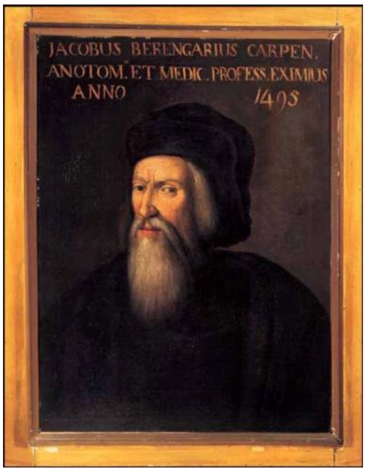

Figure 12.
Berengario da Carpi

Figure 13.
Carpi Treatise

Recognized as one the first to highlight the importance of anatomical illustrations, these are embodied in the brain-encephalic surgery treatise of the sixteenth century (1518): Tractatus de Fractura calve sive cranei (Treatise of skull fractures) (Fig. 13). It was the first modern treatise on BTI, which reviewed the existing literature, made detailed anatomical drawings, and provided explanations of instruments, surgical techniques, and "guidelines" for the conservative managing of some fractures.

He is another renowned historical pioneer in Neuro-traumathology in the Modern Era [43, 44]. He classified skull

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lesions into lacerations, contusions, and perforations, each of which might be associated with a fracture [23, 43, 44]. He described the concept post–concussion headache and made great emphasis on the high frequency of Countercoup fractures. In this era, the term concussion-commotion was referred to any head injury (regardless of the severity) and its symptoms. Since the time of Hippocrates, commotion was associated with “loss of speech”, and Berengario shared this view stated almost 2000 years earlier. Other authors of the time complemented that "the loss of expression was due to a transient loss of consciousness typical of commotion". His interest on Neuro-traumatology was clear and especially with the entity "Commotion", so much so, that he wrote a monograph on the subject. An interesting controversy comes up in the monography regarding the content: ... when the skull is not fractured, some nerves or veins are damaged within the membranes after a sharp movement of the brain, either from a fall or a sudden impact ... This is particularly the case in an excited body, where the skull is more prone to fractures because their brain dries and shrinks ... if the head is shaken by some violent action, patients should be speechless. And through experience this year I saw a case of commotion resulting from vein rupture in the membranes ... [23, 29, 31]. It is very likely that Berengario was describing what is now known as subdural hematoma, depending on the meaning that can be given to those “membranes”. If he was the first or not, it is difficult to discern because Berengario also quoted words of Celsus (25 B.C-50 A.C) as back up of his reasoning: "However, sometimes the bone remains fully intact as a result of the blow, but inside, a broken vein inside the brain membrane releases little blood" . With this data we could attribute the first description of a possible subdural hematoma to Celsus [23, 29, 31, 34]. As an interesting historical cultural phenomenon, Berengario treated the Duke of Urbino, Lorenzo de Medici, who was shot in the back of the head during a battle. The injury did not penetrate the skull but it left a “deep mark” on the left occipital region of the skull, which can be seen in Florence in the Anatomical Institute of the University.

Andrea della Croce was another Renaissance figure who published a work on general surgery and traumathology in 1557, one third of which was devoted to BTI. When there

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was no skull fracture or brain hemorrhage, he called it concussion and developed the concept.

Ambroise Paré (1510-1590) was another great contributor to BTI, the most famous and prestigious French surgeon of the time (Fig. 14). He determined the transition between the last barber-surgeon and the first surgeon. At the age of 13 he became an apprentice barber-surgeon for Dieu Hotel in Paris and focused on performing autopsies to learn anatomy. Ambroise Paré did not have university education and was famous for his dictum: “Guérir rarement, soulager souvent, aider toujours”- Rarely heal, often relieve, and always help [45]. To become a surgeon of four successive kings of France, he is admitted to the School of Surgeons as chief surgeon [8, 23, 43, 44, 45].

Figure 14. Ambroise Paré

Paré considered concussion as a movement disorder of the brain associated with brain edema and hemorrhage as an epiphenomenon. He wrote many reports of head injury cases advising surgeons on how to remove sharp “spikes” [46]. Paré had called Berengario’s “commotion” as concussion or commotion indistinctly and it was after that moment that the term concussion began to appear in medical literature [23, 45, 46].

In 1556, King Henry II suffered a right frontal wound with a wooden spear during a festive event, apparently it penetrated the helmet but without causing fracture in his skull. Paré indicated surgery but the queen (Catherine of Medicis) did not allow it and decided not to do anything as it was suggested by the great anatomist Andrea Vesalio, who had little experience in surgeries. The king died 11 days later and the autopsy described by Paré, revealed a subdural hematoma in the occipital region opposite the front trauma he received [8, 23, 26, 43, 44, 45, 46]. In his book of Anatomy published in 1561, Paré emphasized the importance of Countercoup fractures and posited, quite accurately, that the mechanism could be a subdural hematoma due to a cortical vein tear and the blood accumulated would produce headache, blurred vision, nauseas, and decreased consciousness.

Fallopius (1523-1562), as a professor of anatomy at the University of Padua,

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wrote two books about head injuries and supported the importance of Countercoup fractures and contusions. Whilelm Fabry von Hilden (1560-1624) was a barber-surgeon who treated cronic headache by trepanation and lifted depressed fractures in emergencies. At this time, Hildan designed an instrument to avoid penetration of the brain with a trephine; progress on this technique followed by both Petit and Bell.

Johann Schulthes, a physician born in Ulm-Germany in 1595, was Spigelous's surgical assistant for 10 years and prosecutor from 1616-1623. This allowed him to gain the experience and enough knowledge to write his only book Armamentarium Chirurgicum written, in Latin, and published ten years after his death in 1645. This was the surgical text used in the last half of the seventeenth century which shows how to perform craniotomy after the experience gained in 30 years of war (1618-1648].

Andreas Vesalius (1514-1564) considered the founder of modern anatomy, who published the historical text De Humanis Corporis Fabrica (on the structure of human body) in 1543, also performed craniotomies, but his main contribution was of an anatomical nature.

Jean Luis Petit (1674-1750) and Henri-François Le Dran (1685-1770) were recognized surgeons of the French School along with Percival Pott in London (1714-1788), who described the existence of an interval free of symptoms, but only prior to the development of a post-traumatic infection [47, 48, 49].

In 1751, James Hill from Dumfries, Scotland, defined for the first time the lucid interval related with hematomas on a patient with subdural hematoma. Finally, it is Jhon Abernethy who for the first time delineates the first case of lucid interval in a patient with extradural hematoma (EDH). Later on, in the last half of the nineteenth century , Jonathan Hutchinson and Walter Jacobson's works provide the description and final detail of the lucid interval as we know it today [47, 48, 49].

The importance of a dilated pupil by the third cranial nerve was reported for the first time by Richard Bright (1831) after a confirmation through an autopsy of an EDH. Years later, this piece reaches Jonathon Hutchinson who explained for the first time that this dilated pupil should be caused by direct compression of third cranial nerve [8, 47, 48, 49].

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Contemporary age

This historical period begins in 1789 with the French Revolution and continues to this day. Humanity experimented a real growth and economic, social and cultural change with the development of more advanced societies, and others in the process of developing.

XVIII Century

We have seen that the terms commotion, concussion and compression in brain trauma have been used for centuries in different countries and times. The real clinic pathological distinction of commotion, concussion and compression is introduced by Boviel in 1674 and continued by Jean Louis Petit . Dupuytren (1777-1839) introduced the term concussion describing the three terms but maintaining that they often occurred together. He explains for the first time as a physiopathologic mecanism that the vibration of the skull caused by injury was transmitted to the brain and thus generated a brief loss of conciousness or amnesia [8, 23, 28, 29]. He was also the first to describe the ICP increase due to an EDH, so trepanation was imperative. Percival Pott, aforementioned, was among the pioneers to emphasize that patient's neurological condition determined indication for surgery and not the presence of fracture. Management of concussion in the eighteenth century was very controversial. Francois Quesnay in France (1694-1774), Louis XV's physician, and Pott in England, advocate prophylactic trepanning if there were such "localizing signs", such as pain, while others treated conservatively, pointing out that compression can come on slowly and go without being invasive. The radicals did not take into account the entity "intracranial hypertension without fracture", in fact, when there was a murder by BTI without fracture, the murderer was considered non-attributable.

Jhon Hunter (1728-1793) also made detailed observations on concussion, compression and brain laceration, correlating the level of awareness with variations in pulse, respiration and pupillary response. He did not trepan in case of "isolated concussion states"; he did it in all cases of depressed fracture and opened the dura mater if there was certainty about "fluids" below [8, 23, 26, 29]. Each of these phrases from different surgeons were included after years of experience, where observation and trial were the fundamental scientific tools of the time along with the autopsy.

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19th Century

In this century the napoleonic wars determined a breakthrough in the experience of skull injuries. There were two surgeons, each on opposite sides, Baron Larrey (1766-1842), a great favorite of Napoleon, who already held that cerebellar lesions produced an ipsilateral disorder. On the British side, there was George Guthrie (1788-1856) that wrote on the need to evacuate the EDH and epidural abscess in his monograph, which is mandatory today. He was the first neurosurgeon to write applications that had the neurophysical principles of Pierre Flourens and Robert Whytt on the lesion localization [8, 23, 28, 29, 37].

The great advances in knowledge of neurological function and its brain localization began in the nineteenth century. It is only recently that head injuries are classified by their neurological deficit rather than the type of skull fracture. This is not surprising, since most head injuries were treated by general surgeons who knew little about neurological examination. Although the illustrations in the early sixteenth century showed the anisocoria, this condition was not mentioned until three centuries later, when Jonathan Hutchinson first reported a dilated pupil on the same side as an intracranial clot, and pointed out that it was due to the compression of the third cranial nerve [8, 23, 29, 37]. The discovery of bacteria, the development of asepsis and antisepsis as well as anesthesia gave the final momentum for further growth and study of head injury.

20th Century

The outstanding figure of Harvey Cushing (1869-1939) not only perfected the techniques known in head injuries in the early twentieth century, but also founded the specialty as surgical discipline in his work presented at the Academy of Medicine, Cleveland on November 18, 1904, which he called, "The special field of neurological surgery" [33, 50]. But the greatest contribution made in this century to the history of BTI corresponds to the creation of the Glasgow Coma Scale. At the beginning of World War II, the Medical Research Board in Great Britain, published a glossary of psychological terms commonly used in cases of skull injury: confusion, dazed, semi-coma, mild coma, deep coma, stupor, among others [51]. After World War II, neurosurgical practice focused more on treating tumors and aneurysms of coordination as there was a fatalistic attitude in relation to BTI. Occasionally,

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skull depression was treated and small intracranial hematomas were evacuated because it was thought that little could be done to change the prognosis and outcome. By any means, as the resuscitation and intensive care started to save lives of many seriously skull injured patients, neurosurgeons of the time in Glasgow were challenged to try to reduce mortality, so as to avoid as much collateral damage and improve the survivors' disability. In addition, pathological studies showed that much of the mortality and permanent disability after BTI were potentially preventable, as it is clearly stated in the work of Reilly, "BTI patients spoke and died" [52]. The reasoning they made was very smart: if they had spoken, then they had not suffered irreversible damage, and therefore, they should not have died. The key was that many of those deaths were preventable, and were due to a lack of detection of complications in time and manner.

These concerns led to perform a multicenter study on severe BTI in Glasgow in conjunction with the Netherlands and the USA [53]. But, consequently, this stimulus extended to proceed with a concomitant study, non-traumatic causes of severe brain injury [54]. The major problem was generated when evaluating the state of consciousness. The definitions used were inaccurate with much variability among examiners, which determined certain "subjectivity" and little correlation of lesion, and worse still, they were not measurable variables, complicating the possibility of statistical data analysis. This led to creation and subsequent publication of the Glasgow Coma Scale in 1974 by Graham Teasdale and Bryan Jennett [55] (Fig.15-16).

Figure 15

Bryan Jennett

Figure 16.

Graham Teasdale

Its original and clearly stated purpose by the authors in their original work and subsequent articles, was to clinically assess, in practical and simple manner, the alterations of consciousness and coma produced by any cause, both traumatic and non-traumatic [55, 56, 57, 58, 59, 60]. In its original publication, the scale had ranks from 3 to 14 points [55]. Two years later (1976) its creators modified the flexor response subdividing it as appropriate and

doi:10.18081/2333-5106/015-07/381-409

inappropriate from which is currently known [61]. In 1977, it was applied and validated to define the severity of BTI [53], a fact that marked a world historical moment in the clinical assessment of these patients and determined a great impact to the point that many experts thought that it was created exclusively for BTI. Nevertheless, the scale was validated also for non-traumatic coma in the same year, thus eliminating any confusion in this respect [54].

The Glasgow Coma Scale becomes the most universally accepted classification of BTI. The first severe BTI is defined with a Glasgow score of 3-8 and it is published in 1977 [62]. This, in turn, allowed Coma to be defined as that patient with a score from 3 to 8 [62]. Four years later, Rebecca Rimel applied the scale and defined mild BTI with scores from 13 to 15 [63], and in 1982 the same author completes the clinical spectrum of classification defining moderate BTI with scores from 9 to 12 [64]. This graduation was maintained until 1990 when Stein and Ross [65] used skull tomography to show evidence that those patients with Glasgow 13, classified as "mild", had an abnormal tomography in 40 % of the cases, and 13% requiring surgery. While patients with scores of 14-15, 13-20% had an abnormal tomography and only 5% needed surgery. These results set limits on a substantial change in the classification of BTI: 14-15 was considered mild, 9-13 moderate, and 3-8 severe [66].

Glasgow Coma Scale is, undoubtedly, the most prominent contribution made in the twentieth century to the history of BTI. Through a universal, simple and practical language, it allowed the assessment of brain damage caused by any etiology (traumatic or non-traumatic), define coma, TBI severity, and determine a prognosis in patients with brain damage. All this is due to its creators, Bryan Jennett and Graham Teasdale, who have both left their mark across the world.

Competing interests

Authors declare that we have no competing interests

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