Trepanation, Trephining and Craniotomy

History and Stories

José M. González-Darder

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Preface

Virtually, all cultures over time have opened the skulls of its inhabitants, whatever the reason for it. In primitive or prehistoric cultures, where there are no written records, it is not possible to know with certainty the reasons for this practice. Therefore, almost everything is speculative in this field. In historical cultures, with written records, it is possible to know the reasons, techniques, and fundamentals of this action. The trepanation, trephine, and craniotomy are no more than different forms of cranial opening. The universal human interests that justify this cranial opening along the time may be of a predominantly magical, empirical, or scientific nature. Interest and justification have been changing over time. For centuries, trepanation was itself a treatment that pursued the removal of fracture lines in the skull. Later, the small cranial opening achieved with the trepan or trephine allowed the evacuation of collections located under the bone. Finally, modern craniotomy has become the gateway to the intracranial space, the place where the human anatomy is more complex, delicate, and sensitive and where the neurosurgeon's preferred and exclusive workplace is. In this book, we travel this long road with the aim of writing the first complete and comprehensive history of the cranial opening techniques over time.

This book is the first treaty that addresses this issue with this particular objective. It stands out the cranial opening technique and the instruments dedicated to it over time. We highlight the authors who have contributed innovation to the technical aspects of the cranial opening and the necessary instruments for this. This information is contextualized for a better understanding of the circumstances that require technical improvements and innovations. We highlight the techniques and instruments of success in each period of time and the causes of the failure of designs that eventually failed to flourish. This vast extension of the subject prevents that it has been possible to deepen or investigate in many obscure aspects of the history of the cranial opening.

Every historical study requires a series of conventions. One of them refers to the compulsory division into stages or chapters. Based on cranial opening techniques, we have divided our study into three extensive periods of time linked to the different trepanation, trephine, and craniotomy techniques. Another convention is to assume by the author a personal vision of each of these stages based only on historiographic data. Other conventions are of semantic type or related with the particular cultural view of the author linked with his personal cultural heritage.

Nowadays, the abundant documentary and iconographic information available in the bibliographic repertoires allow an in-depth study of the history of the evolution of the cranial opening. In this sense, we must thank the libraries and directories for the free disposal of these bibliographic funds, nowadays, as public domain resources and easily available in the Internet. Many of these entities have provided high-quality figures for reproduction in this book. By far, the most splendid and generous collaboration has been received from José María Fernández Díaz-Formentí, who has made available to us a superb collection of photographs of trepanned Peruvian skulls. All the images are of great technical and artistic quality, as well as of great scientific value. Others have helped in the labor of organizing the work. I also want to highlight the job of Aurea García, who did the important work of translating the first original text written in Spanish into English. The researcher intensely enjoys the time spent studying a topic and loses the notion of the time that passes. This time is subtracted from the relationship with his closest people. Dolores is the one who has graciously yielded this time to be the author able to write his work, and it is fair to thank her.

Modern craniotomy is the essential surgical technique in Neurosurgery and the one that is the core of this surgical specialty. Knowing the history of every subject is necessary to better understand what is done and what will be done in the future. Therefore, neurosurgeons from around the world can better understand the place they occupy nowadays in the general history of the Medicine and Neurosurgery by reading this book. In the same way, people interested in the development of medical science can increase their knowledge in a seemingly marginal topic, but that follows the general principles of the history of Medicine. Cranial opening can be followed as a case problem. All people interested in the history and the histories of the medical culture can enjoy and evoke past times through by reading this work and, in particular, of the illustrative cases selected.

Valencia, Spain José M. González-Darder

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1 An Overview

At this very moment, or actually at any moment of the day, a lot of neurosurgical interventions that require the patient's cranium to be opened are being performed anywhere around the world. Opening the cranium, just like it is nowadays done with slight variations by neurosurgeons worldwide, is the final result of a great amount of efforts, improvements, solutions and scientific, technical and technological innovations that innumerable surgeons, manufacturers and engineers have provided throughout history. This book reviews the history of all this process, which includes the different geographical, historical and cultural arenas as well as those related to the medical and scientific knowledge. They all need to be assessed and contextualised.

Historically, trepanation, trephine and craniotomy have been the basic methods of cranial opening. Taken out of the neurosurgical field, the term 'trepanation' is immediately associated with an almost ancestral image. Some people will link it to the prehistoric trepanned skulls found in Europe that belong to the Neolithic period. Others bring to their minds the pre-Columbian trepanned skulls found in the Peruvian or Bolivian Andes. From an etymological point of view, the term trepanation only means perforating the bone, preferably the skull, and it does not take into consideration the size, technique or purpose for that action. According to this, any type of perforation or surgical cranial opening can be considered as a trepanation. The cranial openings of our ancestors that were found in the exhumed skulls from the archaeological sites show very different sizes and shapes. Many of them are simple, small and circular holes that resemble modern burr holes. In many other cases, the ancestral skulls show surprisingly big openings or apertures, with several square centimetres. Sometimes old trepanned skulls have almost perfect circular holes with a diameter of several centimetres, an intermediate size between the burr hole and the craniotomy.

1.1 Historical and Geographical Scenarios

The second half of the nineteenth century is a key moment in the history of cranial opening. The first milestone and determining factor is related with the ancestral trepanations. It was the discovery in 1865 of a trepanned pre-Columbian skull by Ephraim G. Squier (1821–1888) in Peru, which was studied in Paris by Paul Broca (1824–1880) [1]. This triggered the scientific interest on European and pre-Columbian ancestral trepanations, which spread among erudite scientists to other primitive cultures later. The second milestone was the launching of the craniotomy. It was the description made by Wilhelm Wagner (1848–1900), 30 years later, in 1889, of the first comprehensive cranial approach designed with the aim of performing a surgical therapeutic action in the

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intracranial space [2]. Wagner named this approach a 'temporary cranial resection' and can be considered as the origin of the modern craniotomy. Wagner's original craniotomy is a technical development of European medicine and means a paradigm shift in the cranial opening techniques. From that moment on the technique of craniotomy developed as a neurosurgical solution to the intracranial pathology approach. However, until that moment European surgeons used to perform trepanations. What was the situation of the cranial opening techniques in Western medicine before the craniotomy then? How did those trepanation techniques come into being? And how was their development until that historical moment?

European and American scientists of the end of the nineteenth century were astonished by the size, amount and quality of the ancestral trepanations from the Neolithic and pre-Columbian periods, which were just brought to light in that time. The first response in many scientific societies of that time was to deny reality and associated them with environmental factors, postmortem actions or a possible fraud. Thanks to Paul Broca it was widely accepted that the trepanations found in the skulls had been performed in live individuals and that they had survived the trepanation. This feeling of excitement and admiration still persists and it is undeniable even for a modern neurosurgeon when he or she looks at a trepanned Neolithic or pre-Columbian skull at a museum.

In the nineteenth century the trepanations performed by surgeons of that time had indeed a smaller size; they were also surprisingly scarce except for war surgery and showed less technical quality than the ancestral ones. To make it worse, patients had a lower probability of survival than the trepanned individuals whose skulls were exhumed from archaeological sites, as the latter were supposed to have a very high survival rate at that moment.

However, we must keep in mind that by the end of the nineteenth century surgeons had already developed specific instruments for surgical trepanations with drills, saws and trephines. By that time the indications and the techniques to trepan had also been described and were gathered in detail in treatises and texts on surgery. This confirms that, although they were limited, small and clumsy, surgeons knew how to perform trepanations and eventually carried them out. This process had started centuries before.

Also, centuries before, in another historical and geographical context, Spanish physicians and surgeons of the sixteenth century were not aware of the fact that in the Inca populations that had been discovered, conquered and become civilised a great amount of sophisticated cranial openings were performed with a high survival rate. Actually, there are no references in the Spanish chronicles of the conquest about this practice. Nevertheless, in that historical moment trepanations were also performed in Spain and in Europe according to a great amount of indications, techniques and instruments that are described in the medical treatises of that time. A handful of historical references that are well documented and that particularly affect kings and people belonging to the nobility or the court show that trepanation was a well-known practice that surgeons who were often trained on war surgery regularly performed.

By that time, scientific fundamentals of medicine, and particularly anything related to trepanations, were based on the *'Corpus Hippocraticum'*, a collection of some 50 works attributed to the Greek Hippocrates of Kos (460–337 BC) and whose originals are not preserved [3]. These texts experienced the different vicissitudes of history and successive handwritten copies were made, translated and probably modified. However, it is wonderfully surprising that the techniques, indications and instruments for the trepanations that are described in the Hippocratic texts are almost comparable to those described and used by the authors of the European Renaissance, like the Spaniard surgeons in America, and that only a handful of modifications or new contributions were added to the medical descriptions made before the nineteenth century, when the ancestral trepanations were brought to light. However, this is very important from a historical point of view as it proves the existence of a link chain that safely paves the way so that modern craniotomy can be considered the final result of the

development of the basis of trepanation that was implemented in the Hippocratic texts.

Unluckily this retrospective historical clue vanishes when we try to find information about the foundations on which the authors of the *'Corpus Hippocraticum'* in turn based to describe in such a precise way the knowledge on trepanations. These foundations, of course, must have been based on the previous expertise. The lack of documents or archaeological remains makes us venture into a speculative territory which could take us, in any case, to the primitive pre-Hellenistic civilisations and, following this way, back to the European Neolithic trepanation.

Therefore, after this quick journey over the trepanation and craniotomy, we can recognise several scenarios where the cranial opening techniques have been developed. Although there are many geographical, cultural and chronological vicissitudes, we can find one core element that is common and connects both the Neolithic and pre-Columbian primitive trepanations. In both cases, they were activities that were carried out within prehistoric cultures; that is, they were developed in a geographical territory and in a period of time that was previous to any written document. These civilisations and cultures are only known by means of certain remains, such as buildings, instruments and human or animal bones. This aspect is essential because, in addition, the remains related to trepanations are scarce. Actually, they are almost restricted to cranial remains. Unfortunately, the existing evidences are not enough to let us reconstruct a sound framework that explains all the circumstances involved in trepanations.

The oldest primitive trepanations refer to a geographical area restricted to Europe, specifically around the Mediterranean Sea, and covered the Neolithic, which started 5000 years BC. This period coincides in Europe with the emergence of agriculture and dies with the introduction of bronze metallurgy (about 2000 years BC). That means it lasted about 3000 years. The trepanations carried out by the American pre-Columbian peoples refer to different Andean cultures, particularly from South and Central America, which existed during many centuries but ended abruptly after the Spanish conquest, that is, at the beginning of the sixteenth century. Leaving the fictitious theories apart, the evident impossibility of communication between both scenes shows us one of the first elements that characterise primitive trepanations: their presence worldwide anytime.

Surprisingly, the general model of these types of Neolithic and pre-Columbian trepanations is repeated in other geographical and chronological fields. Later on, we will see how different primitive cultures located in different places and from different chronological periods, who had no possible connection between them, performed trepanations with a similar fashion, using similar techniques and apparently sharing the same purposes. Trepanations have been carried out by prehistoric cultures and throughout history, even in almost contemporary times and in many places of the world. They have been discovered thanks to archaeological remains. Additionally, there is documentary and even iconographic information on trepanations that were performed in very recent times within primitive Berber cultures from the North of Africa, Polynesian islands and black tribes from Central Africa, such as the '*kisii*' tribe from Kenya. All these trepanations carried out by prehistoric or primitive cultures have elements in common and make up the first historical scenario for the study of trepanations.

The second scenario is the long saga of trepanations since their documentary description in the Hippocratic texts until the modern craniotomy introduced by Wilhelm Wagner. It is a long period of time of more than 2000 years in which the practice of trepanation and the historiographical traces thereof experienced the historical and cultural vicissitudes of the civilisations in which they were carried out. During this period there are documentary and archaeological elements that allow us to track the evolution of trepanations, showing thus that there is a historical continuity. Although there have been dark periods of time, we can affirm that there is no reinvention of the trepanation but a common thread that has always been present. This historical period could be divided in turn into two acts, just like a theatre play.

The Hippocratic texts are the first documentary elements in which the practice of cranial opening is described along with many other medical practices. These handwritten texts, of which the originals are not preserved, experienced innumerable difficulties. Each modification, whether it was just a transcription or a complex translation, was reflected in a new handwritten document that constantly accumulated errors, oversights, changes, contributions, interpretations and other alterations that unavoidably modified the original text. The problem caused by both losing or altering the information contained in the original and widely spreading it throughout the geographical field and time only started to ease with the generalisation of the printing press in the second half of the fifteenth century. In this way, the Hippocratic texts were printed in Latin for the first time in Rome in 1525 and in Greek in Venice a year after, in 1526. Also, in the second half of the sixteenth century, the doctors at that time, who became filled with the pertinent Renaissance scientific spirit, started publishing large treatises on medicine and surgery, in which they described the techniques of trepanation and for the first time included illustrations of the used instruments.

Later on, scientific and particularly medical knowledge and information increased and influenced the trepanations. As it was a sporadic technical and specialised action, the interest thereon was probably not great and very little conceptual improvements were made, as well as in the surgical instruments. The eighteenth century brought a very important historical change: the emergence of science and American scientists in all fields and particularly in Medicine, which had been until then a European heritage. It will be mainly based on Anglo-Saxon ideas and postulates. In the case of trepanations, two different technical styles can be recognised since then. The European one focused on French surgeons and the British one, which was located at both sides of the Atlantic Ocean, which experienced a particular development of the trepanation techniques in America due to the bloody American Civil War (1861–1865).

Therefore, we can split this historical period into two different episodes. The first one starts with the Hippocratic texts and extends until the initial Renaissance with the first printed medical texts that were published in Latin. In geographical terms, it was initially developed in the Mediterranean basin and later spread to Europe. The second one covers a period until the end of the nineteenth century, when modern neurosurgery was born. In the case of the cranial opening techniques we relate this historical moment with Wagner's first description of the original craniotomy. The geographical locations of this second period exceed the European borders and start a phase that we currently call globalisation, as trepanation spreads worldwide along with the overseas processes of colonisation of the European countries.

Finally, the third scenario is completely different. It is based on the cranial opening within the modern neurosurgery field and starts with the description made by Wilhelm Wagner in 1889 of the very first craniotomy. We can assume that this is the ancestor of the current craniotomy. It is a short historical period of about 130 years that is well documented and allows us to track the conceptual, scientific, medical and technological evolution of craniotomy. Accordingly to this historical period, the leading aspect is the technical evolution applied to the cranial opening and how the technological changes become more and more important and quick. The current techniques of cranial opening do not mark the end of the road, but a temporary situation of a continuous improvement process that is relentlessly being carried out by multiple contributions and enhancements that may (or not) have medical, business or commercial success and if so they end up being applied to the neurosurgical practice.

1.2 General Structure of the Book

There is no book that reviews the techniques of skull opening over time and in the different geographical areas where it has been carried out, from the Neolithic trepanations to the present.

The book edited by Arnot, Finger and Smith in 2003 brings together different papers on the subject written by different authors [4]. The review is not exhaustive and many issues remain unchecked or are treated unevenly. Chapters writ-

ten by different authors make that the global vision on the subject is lost. The authors have very high scientific standards, but very few have neurosurgical training. The topic of the craniotomy is not reviewed. Even in spite of the aforementioned, it is the only book that comprehensively addresses the issue of cranial trepanation throughout the ages and cultures.

Other authors also review the topic, although as part of general treaties of cranial surgery, particularly in the late nineteenth century [5–7]. Other similar reviews refer to the history of neurosurgery, where the question of a cranial opening is addressed tangentially [8–10]. Louis Bakay, a neurological surgeon, wrote in 1985 a short book entitled *'An early history of craniotomy'*, which reviews the techniques of cranial opening and the history of the neurosurgery until the early nineteenth century [11]. This lack of a general history of the cranial opening is solved with this book.

Now we are going to detail how the book has been organised so that it can be easily understood. The following chapter describes the cranial trepanation technique used within different primitive civilisations. We prefer the term 'primitive' rather than 'prehistoric', which is more used. The term prehistoric means indeed the period of the history of mankind, and thus the history of any society, culture or social organisation, which was previous to the emergence of writing, which allows to obtain from its documentary information about the issue that is the object of the study. With the term 'primitive' we mean any culture or civilisation that was poorly developed, normally had no writing remains and left more or less comprehensive archaeological information. However, according to the available data it is observed that they lacked a scientific reasoning system and thus the consequences thereof on technologies and beliefs. This allows us to include in this chapter the trepanations performed by some groups culturally primitive, which are almost contemporaneous in time. It has been possible to obtain documentary information directly from these groups, even by means of interviews, direct visualisation of the trepanations and also photographs and films. All these primitive civilisations ended up vanishing or collapsing after a more or less extended geographical expansion and a fairly long historical trajectory. As it has been established, the core element of the trepanation within primitive cultures is the magic-religious aspect. We might consider an empirical component but there is no sign of a medical scientific basis in their actions.

We will later describe the evolution of the trepanation initiated in Greece, which was documented in the book entitled *'On Wounds of the Head'* that belongs to the *'Corpus Hippocraticum'*. By reading this text we can rapidly recognise the elements that let us clearly differentiate this sort of trepanation from the one performed by primitive cultures. The first fact consists of the absence of any magic-religious component in the description of the procedure as the trepanation is suggested as a solution or treatment for an underlying, supposed or evident cranial or intracranial pathology, describing thus the clinical methods to identify and solve it. The *'Corpus Hippocraticum'* is actually the first medical text in which it is possible to recognise a medical technique or procedure as well as the people within society that have the knowledge to perform it. Another differential trait is that there is a written documentary record, although it consists of copies of original texts that were lost shortly after they were written, along with a certain amount of archaeological remains and instruments. This record can be traced reliably until the end of the nineteenth century, when craniotomy was irrupted. As we said, this long period of time has been artificially divided into two stages. The first one covers until the sixteenth century, when the first printed medical texts from the Renaissance appeared. The second one extends until the end of the nineteenth century, when trepanation was rapidly substituted by craniotomy.

Afterwards, the real history of craniotomy starts. This is the neurosurgical intervention that is exclusive and characteristic of modern neurosurgery. From its beginnings, craniotomy has been a technique that completely lacked any magic-religious component and in which the empiric element had a minor role. Actually, the modern craniotomy turns indeed into a part of the neurosurgical procedure to solve the intracranial pathology and in most of the cases is set aside just for the approach. For this reason, it has a separate evolu-

tion from the paradigm shifts in neurosurgical treatments for intracranial pathology and its developments are mainly of a technological nature.

Finally, at the end of each chapter, we collect a large number of original illustrations of the instruments used for trepanation taken from medical and surgical texts reviewed in our work. Comments and translations are also included to understand the illustrations. Some beautiful sheets of trepanation techniques are also reproduced. These illustrations serve as a complement to follow the text and show the evolution of techniques and instruments over time.

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Semantic Features

2

The problem that arises from defining and translating medical terms among different languages, and particularly the techniques and surgical instruments, is extremely important in historic books on medicine and, therefore, in this book. Regarding the correct use of words, we must take into consideration their meaning and etymology.

In English the words 'semantic' and 'etymology' have an easily understanding meaning. Semantic is defined by the Oxford Dictionary as *'relating to meaning in language or logic'* and etymology as *'1. The study of the origin of words and the way in which their meanings have changed throughout history'* and *'2. The origin of a word and the historical development of its meaning'*. In other languages like Spanish, due to the same etymological origin of these words, the meaning is almost the same. The dictionary of the Real Academia Española de la Lengua defines *'semantica'* as follows: *'Del gr. σημαντικός sēmantikós 'significativo'* (From Gr. σημαντικός sēmantikós, 'meaningful'). *1. adj. Perteneciente o relativo a la semántica* (Belonging or related to the semantic field). *2. f. Significado de una unidad lingüística* (Meaning of a linguistic unit). *3. f. Ling. Disciplina que estudia el significado de las unidades lingüísticas y de sus combinaciones'* (discipline in charge of studying the meaning of the linguistic units and their combinations). The same dictionary defines *'etimología'* as follows: *'Del lat. etymologĭa, y este del gr. ἐτυμολογία* etymología (From Lat. etymologĭa, which in turn comes from the Greek word ἐτυμολογία etymología). *1. f. Origen de las palabras, razón de su existencia, de su significación y de su forma* (Origin of words, reason for their existence, their meaning and their form). *2. f. Especialidad lingüística que estudia la etimología de las palabras* (Field of Linguistics that studies the etymology of words)'.

In the best-case scenario, the words we use to describe the old techniques and instruments in contemporary languages are usually the result of a translation made in the nineteenth century from Latin into modern languages of the words that, in turn, the Renaissance translators chose to translate from the by then available texts in Greek, Arabic or Hebrew into Latin. Translating a text long after it was written by its author poses severe semantic problems for translators. Among the translation procedures that can introduce mistakes we can include transliterations, periphrases of different types, univocality or using adjectives instead of nouns. This topic departs from the purpose of this work but we must take it into account when it comes to reading and using certain terms.

We can use as an example the reflections presented by the Spanish researcher P. Conde Parrado about the four translations of Pablo de Egina's volume VI (*'Liber VI De re medica'*), focused on surgery, which were carried out by four different translators in the sixteenth century [1]. The author studies the problems derived from the translation of the more than 50 surgical

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instruments that appeared in the original Pablo de Egina's work, which was written in Greek and the names assigned in Latin by the four different translators. As extreme examples, he focuses on the Latin word *'acus'*, which means 'needle'. This word shows correspondence between all the Latin translations and the Greek original. On the contrary, the Latin term *'scalpellus'* (which means 'scalpel') used by the translators almost never corresponds with any other Greek term written by Pablo de Egina. This shows a real overuse of this term in the Latin translations studied. We must assume that a problem like this was repeated when these Latin translations were in turn translated into living languages of the time shortly after and in subsequent translations, especially those carried out by the end of the nineteenth century.

To solve these problems many medical works from the Renaissance that were written for the first time in vernacular languages include glossaries with medical words and terms and their equivalents in Greek, Latin and, at least, the vernacular language in which they were written. This problem is so real that many authors allude to it at the beginning of their works. Hans von Gersdorff (1455?–1529) was the first one who wrote a medical text in German in 1517, the *'Feldtbuch der Wundarzney',* which already includes at the end three Latin-German glossaries on anatomy (*'Vocabularius Anatomie'*), pathology (*'Vocabularius infirmitatum'*) and herbalism (*'Vocabularius herbarum'*). According to this, we can confirm that by then there was already a need for being very specific in semantic aspects in the medical field. The *'Vocabularius Anatomie'* is a short glossary of descriptive terms relating to human limbs and organs aimed at barbers and surgeons, who unlike doctors did not speak Latin but needed to understand and use Latin terminology. It sometimes introduces Greek and Arabic terms, showing a great number of mistakes. Generally, there is single, double or multiple direct translations but there are anatomical terms that are described or paraphrased. For instance, the dura mater is explained this way: *'dura mater. vsszer grob hirnfell'* (dura mater. vsszer roughly brain-fur). In other cases, the translation is accompanied by an explicative description or a clarifying example. The same strategies are used in the two other glossaries. Von Gersdorff's *'Adendum'*, which contains a total amount of 316 entries, is an impressive etymological and lexicographical work [2].

During the same period Jacopo Berengario (1457–1530) described in his book *'Tractatus de Fractura Calvae sive Cranei'*, which was published in Latin in 1518, the instruments used in trepanations [3]. He specifically wrote that *'instruments are named in so many different ways that sometimes those who hear these names are confused'*. This is why he put the name of each instrument beside each image and admitted the need for a list or some kind of index thereof. This rule was followed at that time by a great number of authors in their works and the names of the illustrated instruments were written near them.

Later on, Laurent Joubert (1529–1582) came back to this issue in his book *'Annotations de M. Laurens Ioubert, sur toute La Chirurgie de M. Guy de Chauliac'*; the title is followed by the sentence *'avec l'interprétation des langues dudit Guy: (c'est à dire, L'explications de les termes plus obscurs) divisé en quatre classes: chacune estant rangée selon l'ordre de l'Alphabet'* (With the interpretation of the languages of the said Guy: [that is, the explanations of the more obscure terms] divided into four classes: each being arranged according to the order of the Alphabet) [4]. The author includes the interpretations of the terms used by Guy de Chauliac (c1300–1368) in the work *'Chirurgia Magna'*, which was published in Latin in 1363 and gathers them in groups of anatomical, pathological, pharmaceutical and surgical terms. He explains the meaning of each term and its correspondent in classical languages, i.e. Greek, Latin and Arabic, and in barbarian or modern languages, such as French and Spanish. For example, Joubert draws in his book a series of bone- and skull-piercing instruments, named as follows: *'Tariere ou Terriee: en grec Trypane, le vulgaire dis Trepan signifie un foret ou villebrequin: c'est en Latin terebra & terebellium'*.

The problem persists over the centuries. A good example of this is offered by the Spanish

historian Víctor Escribano-García (1870–1960), who specifically wrote in his study on the trepanned skull of Enrique I of Castile in 1949: *'de aquí la presente obscuridad y confusión de palabras y conceptos que convendría corregir rectificando el lenguaje quirúrgico, un tanto arbitrario, de libros antiguos y modernos en este capítulo de la cirugía de la cabeza, con definiciones claras de nombres y verbos, como por ejemplo: trépano, trefina, terebelo, taladro, perforador, barreno, tirafondos, craneotomía, craneoplastia, trepanar, horadar, perforar, taladrar, penetrar, agujerear, trabajo entretenido y ya hoy de pura curiosidad histórica y acaso de ninguna utilidad práctica puesto que ha cambiado fundamentalmente ese capítulo, desde la Edad Media hasta nuestros días, en cuanto a la exploración y diagnóstico, a las indicaciones quirúrgicas, al instrumental y a los modos y fines de la maravillosa operatoria endocraneana contemporánea, tan digna de alabanza y de admiración'* (Hence the existing darkness and confusion of words and concepts that would be advisable to solve by rectifying the surgical language, which is quite arbitrary, of old and modern books in this chapter on head surgery with clear definitions of nouns and verbs, such as: trepan, trephine, terebellum, drill, borer, borehole, lag bolts, craniotomy, cranioplasty, to trepan, to bore, to perforate, to drill, to penetrate, to pierce. This is a time-consuming work based on pure historical curiosity but with no practical value because that chapter has dramatically changed the surgical indications, the instruments and the methodology and aims of the contemporary and so worthy of praise and admiration intracranial operative technique from the Middle Ages until the present day in terms of exploration and diagnosis) [5].

Most of the ancient books written or translated to Latin have never been translated to modern languages despite the outstanding longevity of their use among surgeons. The meaning of anatomic or neurological terms and pathological conditions has been different from what we use today. A real problem is that late translations of old medical texts introduce words that were created after the originals were written, that is, neologisms. We are probably going to use this licence unintentionally in this work. It is clear that the list of surgical instruments is different in each given time and it is becoming more comprehensive over time. Thus, it is easy for the translator to employ contemporary nouns to describe old instruments according to their modern use or physical similarities. This way, the old instrument is related to a current word so that the reader of this time can easily understand it. These modifications could repeat in subsequent translations, worsening thus the problem. The consequence is that the reader of the last version of the text has the feeling that those neologisms were actually words used by the author in the original work. And worst, the reader can think that current surgical instruments were real and in use by ancient surgeons because they are named in the translations with modern terms.

As we have already mentioned, the three most important cranial opening techniques over history have been trepanation, trephine and craniotomy. Their etymological and linguistic aspects will be discussed later. There are also some surgical instruments to which the same considerations can be applied, such as the trepan itself and the trephine, along with others of less importance, like the instruments for cleaning the bone and handling the osseous fragments. We will also explain the latter in future pages.

2.1 Trepanation

From an etymological point of view, the term trepanation only means perforating the bone, preferably the skull, and it does not take into consideration the size, technique or purpose for that action. The English definition of 'trepan' by the Oxford Dictionary is as follows: *'NOUN. 1) Historical. A trephine (hole saw) used by surgeons for perforating the skull. 2) A borer for sinking shafts. VERB. Perforate (a person's skull) with a trepan'*. More specifically, in Spanish the Real Academia de la Lengua Española (Royal Academy for Spanish Language) defines *'trepanación'* as action and effect of trepanning *('f. Med. Acción y efecto de trepanar')*; 'to trepan' is

defined as to perforate the cranium or other bone with a healing or diagnostic purpose *('tr. Med. Horadar el cráneo u otro hueso con fin curativo o diagnóstico')*; and finally, 'trepan' is defined as the instrument used for trepanning *('m. Med. Instrumento que se usa para trepanar')*. The French dictionary Larousse defines *'trépan'* as '*nom masculin (latin médiéval trepanum, du grec trupanon). Instrument chirurgical en forme de foret permettant la réalisation d'un orifice dans un os, essentiellement la boîte crânienne'*. According to this, any type of perforation or surgical cranial opening can be considered as a trepanation. However, in the current neurosurgical practice the term trepanation is seldom used, especially with the generic etymological meaning that was previously defined.

The cranial openings show very different sizes depending on their purpose. Many of them are simple, small and circular holes that we name nowadays as burr holes. The term 'burr hole' is used when we refer to a perforation of a small, circular hole, generally with a diameter of less than 1–2 cm, in the skull. It is normally performed with a drill or a burr with a rotation movement that is manually driven or has a pneumatic or electric-powered motor, obtaining bone sawdust.

In many other cases, we found big openings or apertures, with several square centimetres. In the current neurosurgical practice, we generically call 'craniotomy' those big-sized cranial openings. Craniotomy is a modern surgical technique that was born at the end of the nineteenth century to solve the challenges of cranial approach posed by modern scientific neurosurgery. It was then when the use of that term started. Interestingly, the word *'craneotomía'* is not included in the dictionary of the Real Academia de la Lengua Española, whereas 'craniotomy' is accurately well defined in English in the Oxford Dictionary as follows: *'NOUN. Surgical removal of a portion of the skull'*. The current neurosurgical use of the word craniotomy specifically refers to the cranial opening or window which has a big size and variable shape and that has been obtained after making one or several burr holes and cutting linearly the bone existing between them. We normally obtain one single osseous piece that can be reused afterwards if we want to cover with it the osseous window that has been made on the skull.

Sometimes trepanned skulls have almost perfect circular holes with a diameter of several centimetres, an intermediate size between the burr hole and the craniotomy. One way of obtaining these circular holes and with such relatively big size can be by means of an instrument called 'trephine'. The term *'trefina'* does not appear in the dictionary of the Real Academia de la Lengua Española either, but it does in the Oxford Dictionary, where it is defined as follows: '*NOUN. A hole saw used in surgery to remove a circle of tissue or bone. VERB. Operate on with a trephine'*. The neurosurgical use of this term refers to a hole with a bigger size than a burr hole and that is performed on the skull by rotating a cylindrical hollow instrument that has a serrated edge, also known as trephine, obtaining thus a perfect circle from the bone. Historically, the surgical use of trephine as a cranial opening system in skull surgery had its golden age until the end of the nineteenth century. Afterwards it has always been a secondary method of trepanation regarding burr holes and craniotomy. Nowadays, it's almost abandoned. The term trephine was also introduced very late, starting from the seventeenth century, and the origin of this word is unsure and will be discussed later in this book.

Although burr holes, trephines and craniotomies are actually types of cranial trepanation, those terms must be used properly and can't be used interchangeably. Therefore, we advocate that all of those old cranial openings, even the biggest ones, should still be named trepanations. This is how it is normally done in modern literature on this issue. In this book, any type of cranial opening made before modern craniotomy was introduced should be generically called trepanation, including both prehistoric cranial openings and those made by the surgeons before modern craniotomies were performed.

2.2 Trepan and Trephine

The current neurosurgical meanings of the terms trepan and trephine are the following. A trepan is a small hole made on the skull by perforating with a burr or a drill (trepan), producing bone sawdust. A trephine is a larger hole on the skull that is made by rotating a cylindrical hollow instrument that has a saw on its free edge, called trephine. Once the perforation is over, a perfect disc of bone is obtained.

The different meaning that we nowadays give to these different types of cranial perforations was not so clear throughout history. Unfortunately, the use and meaning of the terms 'trepan' and 'trephine' have changed over the centuries and they have also had different meanings for different authors and in different languages. We can affirm that the term trepan (in Latin *'terebra'*, from Greek language *'trupanon'*) was used by ancient authors to refer to an instrument used for making cranial drills with a small diameter. The *'modiolus'* was the tool used for making larger drills with a perforation element that was similar to modern trephine crowns. Curiously, the word *'modiolus'* disappeared from the medical texts from the seventeenth century onward as it was substituted by the word trephine.

The term 'trephine' is included in the prestigious Oxford Dictionary. It is accurately defined as follows: *'Trephine: A hole saw used in surgery to remove a circle of tissue or bone'*. Equivalent terms are used in Spanish (trefina), French (tréphine), German (Trephine) as well as Italian (trephine) and Portuguese (trephina). However, the term *'trefina'* is not defined in the Dictionary of the Real Academia de la Lengua Española (Royal Academy for Spanish Language).

The meaning and use of the term trephine raise interesting questions concerning semantics and linguistics. The word trephine is most certainly a late word as it appeared in the seventeenth century. There are two opposed opinions concerning the person who introduced this new word in cranial surgery. It is broadly accepted that it was Girolamo Fabricius d'Acquapendente (1537–1619) who first presented a new instrument with three legs that was used in trepanations. It was a drilling instrument that he named *'trypana'*. This instrument had three short shanks that run from the centre forming a star. One of the arms ended in a screw tip and it was used to screw it to the skull bone in order to lift it. The other two arms had a more or less enlarged and flattened end and were used to lift the bone fragments by levering them. As the instrument had three tips it was called in Latin *'tres fines'* ('three tips') [6]. It has been accepted that the word 'trephine' comes from the adulteration of the term *'tres fines'* into *'trafina'* in Italian and subsequently *'trefina'*. The Spanish medical etymological dictionary of the University of Salamanca states under the entry *'trefina'* (trephine) that *'no se han encontrado formantes en español. Viene del latín 'tres fines' ('tres puntas') 'de un instrumento para trepanar inventado en el s.XVI por Fabricio de Acquapendente'* (no morphemes have been found in Spanish. It comes from Latin 'tres fines' (three tips), which is an instrument used for trepanning invented by Fabricio de Acquapendente in the sixteenth century). However, this instrument described by d'Acquapendente did not allow making perforations and did not resemble a trephine at all.

Other authors suggest that the origin of the term trephine comes from John Woodall (1570–1643). This author described an instrument that improved the existing trepans in 1639. He called it 'traphine' because it had three edges. This word would ultimately become 'trephine'. The instrument described by Woodall could be used with one hand. It had a T shape, a transverse handle and a mounted shank on one edge with a drilling crown that had a truncated cone shape. He called the instrument *'tribus finibus'* or *'tres fines'*, meaning that it had three tips or edges: two of them forming the transverse handle and the other one in the drilling crown. This instrument, therefore, looks like what we now understand as a T-handle trephine [7]. It is obvious that this tool is not the same one that was described by d'Acquapendente at all. Thomas Wilson Parry

(1866–1945) supports this origin of the word trephine by Woodall, but introducing this very singular comment: *'Trephining: Latin, Tres, three and fines, ends. A terrible word concocted by Woodall (died 1643) when he gave the 'trepan' a handle and evidently decided that the new word must bear some resemblance to the old one, though the one was Greek and the other Latin'* [8].

The terms *'trepanning'* and *'trephining'* were mistaken and used interchangeably in English medical and historical literature. The latter term has a greater acceptance in English language and ended up becoming the word that means any osseous perforation, particularly the cranial ones. The translation of older texts written in other languages into English in the nineteenth century (particularly old medical texts written in Latin) was the reason why the term trephine was introduced and associated with such a broad meaning. Careless readers might think that the word trephine was used in the old original texts. An evidence of this confusion is shown in Benjamin Bell's (1749–1806) book, titled *'A System of Surgery'* where he specifically points out that the only difference between the *'trepan'* and the *'trephine'* was the handle, as *'It (the trepan) differs from the trephine only in the handle being worked like a carpenter's wimble'* [9].

The terminological confusion between trepan and trephine has been present along centuries and persists nowadays. In a paper reviewing the history of trepanation in Africa published in 1994, American neurosurgeons Rawlings and Rossitch transcribe the semiology of the term's 'trepanation' and 'trephination' in this following confusing way: *'Trepanation, or trephination, is one of the most fascinating and ancient practices in the history of medicine. The word trepanation is from the Greek trypanon meaning a borer whereas trephination is a French variant. Trepanation describes scraping, whereas trephination connotes drilling of the skull. For all intents and purposes, they are interchangeable and imply a depression or perforation in the calvarium'* [10].

A similar problem often happens in French medical and historical literature with the terms *'trépan'* and *'trephine'*. The term *'trépan'* keeps its general meaning of cranial perforation in French literature. Therefore, trepanation was generally called *'L'operation du trépan'* in French medical literature of Modern Ages until the end of the nineteenth century. The French authors also often used the words *'trépan'* and *'trephine'* interchangeably, although the difference between both instruments was related to the handle rather than the bone-cutting element. Hence, French authors normally prefer the term *'trépan'* when referring to the driller with brace handle and *'trephine'* for the T-handle driller, which corresponds to the English ones (*'trépan anglais'*). We now include a fragment of the book *'Traité complet de l'anatomie de l'homme'*, which was written by Jean Marc Bourgery (1797–1849). It perfectly shows this issue. An illustration shows two trepanation instruments [11]. One of them has a brace handle and the other a T-shaped handle. Both have the same cylindrical cutting crown mounted on one edge. He calls the first instrument a *'trépan'*, but when he describes the drawing that represents the perforation instrument with a T-shaped handle he calls it *'Tréphine (ou trépan anglais)'*. He states that 'this instrument is nothing but a trepan than can be held with one hand by its transverse handle. Apart from this, the accessory parts of the main instrument are the same'. Other French authors expressly refer to the instruments in the same way. They assimilate the name *'trépan'* for the brace-like driller and *'trephine'* for the T-handle driller, regardless of the drilling instrument that was coupled (normally a trephine crown in both cases of that time).

We are going to use the term trephine in this book when referring to the drilling instrument and the technique that makes a circular cranial opening with a hollow instrument that has a saw on its edge (trephine). It allows obtaining a disc of bone, regardless of the type of handle (brace-like or T-shaped handle). In the following pages will try to describe the devices, detailing in each case the handling and the perforating parts of the instruments.

2.3 Craniotomy

Ancient surgeon only occasionally enlarged the cranial opening obtained after making the initial trepan or trephine in that time. However, as the modern concept of craniotomy did not exist we are going to refer to these large cranial windows generally as trepanations.

The term 'craniotomy' is used in this book meaning a surgical intervention that involves making a cranial opening or window of a large size and with a variable shape. This is achieved by making one or several burr holes and a linear cut on the bone existing between them. It aims usually to carry out a therapeutic surgical intervention in the intracranial space. The first modern craniotomy accomplishing all of these requirements was described by Wilhelm Wagner (1848–1900) in 1889 [12].

The term *'craniotomy'* is defined by the Oxford Dictionary as follows: *'Noun. Surgical opening into the skull'*. The Oxford Dictionary also includes the meaning of the ancient technique that involved breaking the foetus' skull in the birth canal so that it could easily come out (*'Surgical perforation of the skull of a dead foetus to ease delivery'*).

The lexical components of the term craniotomy are *'kranion'* (skull, head) and *'tome'* (cut). The term *'craneotomía'* is not defined in the dictionary of the Real Academia de la Lengua Española (Royal Academy for Spanish Language). The medical etymological dictionary of the University of Salamanca states that the term *'craneotomía'* has a modern origin and comes from the English (*'Craneotomía' (Cirugía) Apertura quirúrgica del cráneo. Leng. Base: gr. Neol. S. XX. Docum. En 1929 en ingl.)* ('Craneotomy' (Surgery). Surgical opening of the skull. Original language: Greek. Neologism. Twentieth century. First documented in 1929 in English language). This etymological consideration is not correct as the terms *'craneotomie'* and *'craniectomie'* were used decades before in medical texts by many French authors. At the end of the nineteenth century, in year 1893 [13], the French author Lèon Gallez (1864–1898) mentioned the craniectomy and the trepanation technique as well as the increasing use of the former term in his work *'La trépanation du crâne'*, where he wrote: *'J'estime qu'il est préférable de la dénommer craniectomie, terme ne désignant que l'acte opératoire lui-même, abstraction faite des instruments à utiliser pour son exécution. On observe, en effet, l'heure actuelle, la tendance qu'ont les chirurgiens à substituer cette nouvelle appellation à l'ancienne'* (I think that it is better to call it craniectomy, a term which designates only the operative act itself, apart from the instruments to be used for its execution. At present, we observe the tendency of surgeons to replace this new name with the old one). Accordingly, George Marion (1869–1960) established in 1905 in his book *'Chirurgie du Système Nerveux'* that the cranial opening can be carried out *'Par relèvement d'un lambeau osseux circonscrit de façon variée; l'opération prend alors le nom de craniectomie à lambeau, on devrait dire plus exactement craniotomie'* (By raising a bone flap circumscribed in a variety of ways; the operation then takes the name of flap craniectomy, we should say more exactly craniotomy) [14]. Many other French and English authors used both terms 'craniotomy' and 'craniectomy' interchangeably in that time.

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Part II

Magic Times. Trepanation in Primitive Cultures

Deseo insistir que con estas trepanaciones no se podría solucionar hoy en día ningún proceso patológico endocraneal, con la excepción, un tanto discutible, de un hematoma o absceso

Domènec Campillo (1977–)

3 Facts and Myths of Primitive Trepanations

3.1 Trepanations and Primitive Cultures

We can state that trepanations are the oldest surgical interventions we have evidence of [1, 2]. It is also possible to point out that almost all human cultures, in almost all geographical locations and along the time line, have carried out any type of cranial opening with very different purposes, no matter whether they were known or unknown. In this chapter we are going to focus on cranial openings or trepanations carried out within primitive cultures, including cultures worldwide and in different chronological periods, particularly those performed during the European Neolithic 5000 to 3000 years BC, the American pre-Columbian times until the Spanish Colonisation during the sixteenth century and by some Oceanic or African tribal cultures during the nineteenth and twentieth centuries.

We are going to consider as primitive cultures those ones that meet the requirements specified below. First, they lack any written document; that is, they are prehistoric. It is noteworthy that, for example, the Inca civilisation, which was very developed, did not have any known writing system, although the *'quipus'*, which were some sort of macramé made of cords with knots, were supposed to have such paper. Actually, some primitive cultures do have writing remains, such as the Aztec, the Maya or other Mesoamerican writings. However, they cannot be read as they have just started to be decoded. The lack of writing remains is the reason why almost all what is known from these cultures concerning trepanations comes from the study of human bones and some marginal archaeological remains that let us contextualise the findings. Another feature is that these civilisations carried out certain rites with their corpses. To preserve the cranial remains it is necessary to bury the corpses. This is the only technique that allows to preserve the trepanned osseous remains over time so that they can be studied. Other types of mortuary rituals, such as cremation, make it impossible to preserve the bones. In those cases when there are no written documents, it is unfeasible to determine whether trepanations were carried out or not. Another characteristic element of primitive cultures regarding trepanation techniques is that they used solutions and instruments that were suitable for each type of drill and in keeping with the materials and technologies of their geographical and historical situation. In general, primitive cultures are also characterised by settling in restricted geographical locations with few or very limited trading/cultural activities with the nearby peoples or those ones living in the same period. This is why we cannot obtain information from them in an indirect way. As a consequence, an essential, final, and common feature of primitive cultures is that many aspects of trepanation are unknown or are based on speculations or theories. Hence, we must affirm that actually it is not known why the

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trepanations were carried out or the purpose thereof. In this regard, the only link between these primitive trepanations is that they were some sort of very primitive medicine of a magical or religious nature with some undeniable empiric elements.

According to these criteria, primitive cultures can be either extinct or contemporary. As for the latter, they show all the general features that have been pointed out. Fortunately, we have, in some cases, direct testimonies of the trepanations provided by reliable independent witnesses. They are even documented by means of photographs or films.

It is now important to understand, narrow and adequately use the term 'trepanation'. From a strict semantic and etymological point of view, we have defined the trepanation as a surgical osseous drill. Trepanation refers to drilling any bone of the anatomy. Cranial trepanation specifically refers to trepanning the skull and particularly the cranial vault, with no connotation regarding the size of the cranial opening or the techniques used to carry it out.

The modern definition of the term 'trepanation' also means that the drilling must be surgical; that is, it must have a diagnostic or therapeutic purpose. However, in the cranial openings carried out by primitive cultures we cannot accurately prove that there was a diagnostic or therapeutic aim beyond the magical, religious or empiric objective. For this reason, when we use the term 'trepanation' in this book within the context of primitive cultures, we will completely remove from it any possible association with any kind of medical or surgical intervention. For this same reason, we will not use the term 'surgeon' when referring to the person who carries out the trepanations within primitive cultures, let alone the term 'neurosurgeon' when referring to the person in charge of cranial trepanations.

We will subsequently review the trepanations carried out in these primitive cultures. We will highlight the technical and technological aspects of such practices, without forgetting the cultural context in which they were performed. Trepanations in primitive cultures are also known as 'prehistoric trepanations' or 'ancient trepanations' in other works or studies.

3.2 History of 'Prehistoric Trepanations'

It is nowadays accepted that the scientific interest on trepanations of primitive peoples arose from Ephraim George Squier (1821–1888) and his convenient relationship with Paul Broca (1824–1880) [2–5]. Squier was an American diplomat and archaeologist who, after completing a commission from the American Government in Peru, spent the remaining available time focusing on his passion for anthropology and travelling around the country. During his trips he got a skull on which he observed and described the evident signs of a frontal cranial trepanation. Such skulls had been found in the area of Cusco (Peru) and belonged to the pre-Columbian period. Afterwards, it was dated from the years 1400 to 1530.

Squier described how he got the skull, actually a gift of the Señora Zentino in his book *'Peru. Incidents of travel and exploration in the land of the Incas'*, published in 1877 (Squier [6]). Squier writes: 'In some respects, the most important relic in Senora Zentino's collection is the frontal bone of a skull, from the Inca cemetery in the valley of Yucay, which exhibits a clear case of trepanning before death. The senora was kind enough to give it to me for investigation, and it has been submitted to the criticism of the best surgeons of the United States and Europe, knowledge of surgery among the aborigines yet discovered on this continent; for trepanning is one of the most difficult of surgical processes. The cutting through the bone was not performed with a saw, but evidently with a burin, or tool like that used by engravers on wood and metal. The opening is fifty-eight hundredths of an inch wide and seventy hundredths long' (Fig. 3.1).

After coming back in 1865 he presented the skull to the New York Academy of Medicine so that it could be studied. On its final report, the Academy showed their complete scepticism about the fact that the trepanation had been carried out before dying. Squier, who was disappointed after the report, sent the skull to Paris so that it could be studied by Broca, who was considered by then a worldwide reference in terms of