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STATE OF THE ART

The Basic Steps of Evolution of Brain Surgery

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ABSTRACT

Objective and conclusion: *Neurosurgery is probably the most constantly developing specialty of all times. Its dimension is enormous and its history, Ancient. The evolution of neurosurgery from the Mayan and Egyptian periods to the Renaissance and the 21st century was the result of many physicians and patients whose experiences lead to the revolution of modernization. Today, the field of neurosurgery is continuously expanding, aiming to introduce knowledge and technologies that could provide a new futuristic wave of medicine.*

Methods: *Given this background, our team selected relevant data from Medline published between 1936 and 2017.*

Results: *We included 91 articles on this topic, all of them providing enough information about the revolution and progress of brain surgery through the centuries as well as its potential expansion in the future.*

Keywords: neurosurgery, futuristic, progress, modernization.

BACKGROUND

The journey of brain surgery is long. Beginning from the Ancient times with Inca (1), Hippocrates and Galen, through the Renaissance and World Wars until recently, neurosurgical procedures have constantly been performed, as it has always been talked about neurosurgery (2, 3). But for the first time in centuries, in 1900, H. Cushing brought modern neurosurgery into the world (4). Since then, neurosurgery has reached such levels of development that it may be considered to be one of the most futuristic specialties of all times.

METHODS

We searched Medline for literature on the history and evolution of neurosurgery, and selected all kinds of articles and books published between 1936 and 2017. Our aim was to show the excellence and progress of this specialty through all times as well as the tremendous impact of technology, by pointing the most marvellous steps. We considered the events that have been marking neurosurgery as a specialty, a revo-

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lution and a therapeutic method, not as part of the neuroscientific research and theories, our intention being to show that neurosurgery is a futuristic specialty which not only has a long history but also a promising future.

We included articles that provide this information and thoroughly explain the expectations and the process of changing of the brain surgery. It should be highlighted, however, that side effects and ethical issues were not considered in this review, although they have been explained in the majority of the published articles.

On the other hand, we excluded articles that were not written in English, those that did not offer sufficient information and articles stemming from an unclear source. Since the focus was on the brain surgery, we have also excluded articles emphasizing issues related to spinal cord and surgery.

Neurosurgery trough the ages

Launching from the Ancient times, neurosurgery is believed to be the oldest medical "specialty" of all times (3). And as the history has written itself, "trepanation" of the cranium was thought to be the first neurosurgical procedure (3). Its use was mainly for headaches, seizures, mental illnesses, bad spirits and traumatic brain injuries (5). Together with cranioplasty, it seems that they have been performed since the period of Inca, counting that head and spinal cord injuries existed since the beginning of time (6, 7) (Figure 1). Interestingly, cranioplasty was mentioned after the Inca, again in the Renaissance from Fallopius, but not in-between (8).

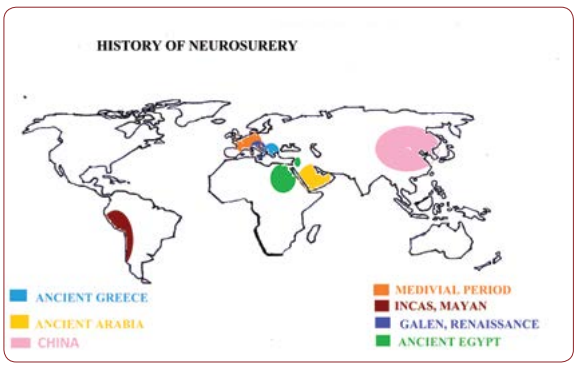

FIGURE 1. History of neurosurgery

After the Incas, a record of the neurosurgical procedure was preserved on Egyptian papyri, which described for the first time sutures of the skull, cerebrospinal fluid and intracranial beat as well as the very first neurosurgical operation (9). But Edwin Smith papyrus is actually a very detailed presentation of spinal cord trauma with its mechanism and symptomatology, which makes it the former record on spine and brain injuries (10, 11).

Although trepanation was believed to be rare in China, recent studies (12, 13) show that this procedure was not only dating back to 10 000 BC, but it was also very common, suggesting that trepanation and neurosurgical procedures were performed worldwide and in parallel. The first known Chinese surgeon, Hua Tuo, is thought to be a great contributor to the field with his practices for headache, paralysis and assumed brain tumors (14). Data from India (15) show that neurosurgical procedures were born later, but the Indian surgeon Sasruta gave the first detailed description of surgical instruments and was also the first known physician to achieve a successful entrance of the skull.

Regarding the trepanation in Oceania, skulls were found with the characteristic sign of the procedure, but it could not be dated to a certain time period (5).

However, official expansion of the neurosurgical field was observed in the Greek "Golden Age" with Hippocrates (3), whose contribution to the field was enormous; not only had he described the localization of an injury on the skull/brain and subarachnoid haemorrhage, but he has also offered the first documented indication for the use of a threpanon. Through the Roman and Byzantine periods, many other names were written in the history such as Celsus, Rufus of Ephesus and Galen, who described the cranial nerves and the brain as organ of thoughts as well as techniques for treating head trauma. But what made Hippocrates, Galen and Celsus the so-called "Giants of Medicine" was their contribution to the management of traumatic brain injuries (16).

Later in history, the Arabs played a significant role to the growth of medicine. Names such as Avicenna and Rhazes changed the European universities with their works (17), but Abbas and Albucasis were those who have actually influenced neurosurgical progress (3, 18, 19).

During the Medieval period, as in every other time period, there were many contributors to the

field. However, only few changed the mechanism of thought, and it is worth mentioning the names of Theodoric Borgognoni of Cervia, with his antiseptic surgical technique and observation of wounds healing, Lanfranchi of Milan, and William of Saliceto, who introduced the surgical knife (19).

The bridge to the modern neurosurgery

Despite progress in these centuries, development has actually begun after the XVIth century with the anatomical descriptions and experiments of Leonardo da Vinci, Berengario da Carpi's work on head trauma (actually the first book dedicated exclusively to head trauma) and his detailed description on the ventricles, Ambroise Paré – also known as the "father of modern surgery" – and his input to the understanding of head trauma, Andreas Vesalius' work on the mechanism of head trauma and the role of skull to protect parenchyma, and many others' contributions that have been constantly raising the level of neurosurgical knowledge (3). This blooming is understandable, due to the first published documentation for neurosurgical procedure dated in 1561 (20). Even bigger development was seen in the XVIIth century, when educational progress was observed, *e.g.*, improvement in anatomical knowledge, mainly the recognition of Willis's circle and vascular supply of the brain; operation and techniques on intracranial hemorrhage of babies; first detailed description of surgical instruments and head trauma in children (3).

The continuance of such an increasing flourishing has been also observed in the XVIIIth century, with the improvement of medical and diagnostic examination, vaccines to "Pott's puffy tumor", head injuries and osteomyelitis of the skull (3, 21). Post-surgical infection was recognized as well as many other basic issues for us surgical complications and problems (3). Various operative techniques and approaches have been described in the effort of improving patient's health (21). Lastly, but not least, for the first time in the 18th century an operation on brain abscess was described, with detailed explanation of the cerebrospinal fluid (3). Another step forward was the explanation of brain pulsation as vascular and the cause of concussion (21). But head trauma and injuries, as always, have been in the first row among neurosurgical patients.

Theories about localization on the skull/brain have many sources. Ancient philosophers and physicians have tried to explain how the brain was working, but this aim was successfully achieved only in 1885 (2), when also for the first time a brain tumour was localized and surgically resected. In a similar concept, Broca, a Giant of neuroscience, achieved the functional localization of the brain and was one of the first physicians to explain the archaeological findings of trepanation of the skull (22).

Modern neurosurgery

Despite the fact that neurosurgical procedures have been performed in all ages, modern neurosurgery began with Cushing, in the USA (4). Color anatomy atlases of the brain and spine appeared in the period between the XIXth and the XXth centuries (3); remarkable was the one illustrated by J. Cruveilhier, who also expressed his observation on pathologies such as spina bifida, haemorrhage of the spinal cord, angle tumour in the cerebellopontine area, sclerosis, atrophy of the muscles and meningioma (3, 23, 24) – and it could be observed with the performance of craniotomy with modern techniques (2). Here "speak" the names of those physicians as loud as their achievements. One of them was G. Heuer (25), student of H. Cushing, who expanded craniotomy for an enhanced approach to the tumour; V. Horsley, who performed the first resection of spinal cord and pituitary tumour; FT Paulm, with performing decompressive craniotomy; Krause, who performed craniotomy to remove a bullet; Kiliani, with his intradural approach, and McArthur, with his innovative approach to the pituitary (2).

Modern history, in contrast to Ancient times, has not begun similarly worldwide. This is supported by the study of Khamlichi (16), who reports that modern neurosurgery in Africa begins a half century later. This delay of modernization worldwide could be explained by the lack of understanding of brain anatomy and function until recently (3). And as we see, the introduction of technology, the knowledge that is offered, and last but not least, all these studies that help refreshing our statement on therapy management,

technical approach, etc provide the required basis for progress.

1. Microscope

Starting from technology, many new devices make it possible for the neurosurgical procedure to become safe and efficient. Regardless of the fact that the microscope was invented in the XVIth century, its modernization came with Zeiss and Abbé in the XIXth century. Years later, it was adopted in the surgical field, and in 1957, the first neurological surgery was performed by Th. Kurze (2). His admirer, G. Yaşargil, following the idea of Kurze and using the microscope, developed microsurgery as primary discipline in modern neurosurgery (2). In the study of Sanai *et al*. (26), a rate of 97% efficiency in patients treated with a microscope for vascular disease was observed. Another application of the microscope is in spinal surgery (27), transsphenoidal surgery (28), nerve reconstructive surgery, tumour resections (29), etc. Last, but not least, the use of microscope decreases the physician's exhaustion (30) (Table 1). A recent innovation is the hybrid of microscope and endoscope for tumour management (31). This fusion helps decreasing the blind stain, while increasing the effectiveness and prognosis, especially in children. But actual futuristic prospective of the microscope is shown by Kantelhardt *et al*. (32), who report the use of fully robotized microscope for neurosurgical operations on prototypes. Based on its characteristics, it is expected that this type of microscope could evaluate data on the structures of the parenchyma and volume transformations during surgery. Robotization of the microscope could enhance the security and effectiveness of the procedure in case of deep lesions (33) (Figure 2).

FIGURE 2. Microscope for neurosurgical operation

2. Endoscope

Regarding the birth of endoscopy in neurosurgery, in 1910, V. L'Espinasse used the endoscope for hydrocephalus. A few others performed endoscopic procedures, but enthusiasm was not enough. The invention of advanced design endoscope, however, made it possible for G. Guiot to carry out the first neurosurgery (2). Later, in 1923, endoscopic ventriculostomy was performed (34). Innovations keep appearing with Fukoshima, who made the endoscopic technique not only for surgery, but also for diagnosis (34, 35), and with others, who used the endoscope to expose the spinal canal (34, 36, 37). Enhancement of the endoscope is observed with H. Hopkins, with his work on improving the instruments (34). But modernization came with Vries (34) and his ventriculostomy's work, Powell (38) and Auer (39), with their work on brain biopsy and drainage of the tumour. Nowadays, the endoscope is used mainly for the ventricular system, biopsy and when required in operations (34). Based on the study of Divitiis (40), endoscope's future might be in its use in brain aneurysms, tumours and angiomata (Table 1). According to current data, the endoscope is even more frequently used with the stereotactic technique. In those cases, endoscopy is hybrided with YAG-laser in 2-D/3-D plan, which ensures visualization of the ventricles, evaluation of the resection and homeostasis during surgery, and last but not least, less invasiveness (41). Because of that, it could be used for cystic brain lesions (42), biopsy, haemorrhage, drainage and ventriculoscopy with no obvious drawback (43), ependymal

Microscope	Endoscope	Ultrasound
- Good view of the posterior surface of vascular and neural constructions - Transsphenoidal surgery - Vascular - Spinal surgery - Tumours - Reconstructive nerve surgery - Cysts - Bypass - Foramen Magnum pathology	- View of angles, Meckel's cave, internal acoustic meatus, vagal meatus, glossopharyngeal meatus, junction of nerves - Superior view of nerves and vessels and their relationship - Transsphenoidal surgery - Ventricular - Biopsy - Tumours - Haemorrhage	- Tumours - Biopsy - Skull –base surgery - Vascular - Endoscopy - Resection – guiding and control - Deep brain stimulation - Spinal cord

TABLE 1. Indications of the microscope, endoscope and ultrasound in neurosurgery

giant cell astrocytoma (44), hematoma (45), colloid cysts (46) and tumours in the ventricular system (47). But the newest invention of the endoscope is the co-operation with robotics that have been used until recently for microscope neurosurgeries (48).

3. CT, MRI

Computer tomography (CT) and its introduction in the 1960s provided better diagnostic opportunity and perisurgical results (49). Its current indications regarding neurosurgery are multiple such as CT routine, angiography, follow-up, headaches, haemorrhage, tumours and intracranial pressure (50) (Table 2).

Magnetic resonance, on the other hand, was invented in some stages. But the first statement for magnetic resonance imaging was in 1974 (51). A few years later, with the development of intraoperative MRI, there was an improvement of neurosurgical treatment (52). Its indications are also numerous (see Table 2 and Figure 3).

CT	MRI
Angiography, routine examination, haemorrhage, stroke, headaches, intracranial pressure, trauma, intraoperative guidance, hydrocephalus, and when MRI is not available	Ischemia, infarction, infection, haemorrhage, tumours, trauma, seizures, cranial neuropathies, headaches, neurodegenerative conditions, congenital pathologies, intraoperative guidance, hydrocephalus

TABLE 2. Indications of CT and MRI in neurosurgery

FIGURE 3. Image-guide for neurosurgical operations

4. Endovascular technique

In this order, in the 1970s, Serbinenko *et al.* (53) introduced for the first time the endovascular catheterization of brain aneurysm with balloon. Later, in the 1990s, the coiling for brain aneurysm repair was introduced by Guglielmi *et al.* (54), followed by methods with balloon and coils (55) and coils and stent (56). Nowadays, there are plenty of surgical and non-surgical methods that provide the best possible therapy for brain aneurysms (57); the non-surgical ones, however, are used with imaging technique. Another implication of the endovascular technique is the therapy of arteriovenous malformations (AVM) and fistula (58).

5. Ultrasound

Continuing with modern neurosurgery, a significant role is played by ultrasound (US). The earliest ultrasound was invented after World War II for medical diagnosis (59). Few years later, the two-dimension ultrasound was invented, and in the 1960s it was applied for imaging of the brain. In some years, Olaf von Ramm and Stephen Smith invented the 3-dimensional ultrasound (60). Based on the report by Unsgaard *et al.* (61), its use in neurosurgery might be intraoperative to revise the preoperative images in neuronavigation or to direct in 3-D dimension. The 3-D ultrasound has plenty of indications, but its use in brain tumour resections is found extremely helpful, as well as its novel application in intraoperative guidance during deep brain stimulation (62, 63) (Table 1). On this perception, in 1982, the transcranial Doppler, representing a type of US, applied for the first time measures of the intracranial blood flow's speed and was requested in case of trauma or vascular disease (64, 65). Futuristic expectations of the US are found in the 1.5 probe, which may increase the quality of the image; strain images that would provide information about the elasticity or in contrast imaging (61).

6. Laser

Another invention, assigned to neurosurgery, is the laser. Former, it was invented in 1960 by Th. Maiman (66). The first use of the ruby laser in neurosurgery is performed on glioblastoma by Rosomoff and Caroll (67). And a few years later with the declaration of CO_2-laser was performed a resection of tumor of the brain (67). The differences among them is based on the penetration of the tissue, and because of that, they have different indications (66). A study with 650 operations, made by Ascher *et al.* (68), and years later, a study conducted by Jain (66) suggested that CO_2-laser is suitable for tumours, vascular diseases, abscess, craniostenosis, spine surgery and peripheral nerve surgery. Observations of the

procedures show that laser incisions are less damageable, i.e., less hemorrhageable and more sufficient. On the other hand, Nd-YAG laser, because of its penetration's beam, is right for coagulation, vascular procedures and anastomoses of nerves. Argon laser, however, has uncertain indication of brain tumour therapy (66). New indication of laser's use is found in the surgery of epilepsy (69) and laser endoscopy for tumour diagnosis (70).

7. LED

Light Emitting Diode not only was introduced to neurosurgery in the same decade with laser, but also it has a similar mechanism of action. Its application, however, is somehow different. LED is used in injury (brain, spinal, nerve), wound healing and probably as neuroprotector (71).

8. Radiosurgery

Radiosurgery is a recent novelty in neurosurgery. Even though the stereotactic apparatus was invented long ago, it was only introduced to the surgical field in 1947 by Spiegel and Wycis (72). Lars Leksell, on the other hand, invented the gamma knife for lesion inside the head. Nowadays, the use of γ-Knife and CyberKnife is expanded mainly in tumors, brain metastases, trigeminal neuralgia, arteriovenous malformation (73), brain stem lesions, and in functional neurosurgery (74).

9. Robotization, biotechnology, nanotechnology

What actually stands on the border of new generation tools in neurosurgery is robotization, biotechnology and nanotechnologies. Robotics has been introduced in the neurosurgical field not so long ago before, having as a prerequisite the capability of robots to increase the neurosurgeon's potential (75). But despite its help in difficult surgeries, robotics have been challenged in the anatomical structures of the head and because of that, it is mainly used in the stereotactic field, for intraoperative imaging and better "hand-control" (76, 77).

On the subject of nanotechnology, first presented by E. Dextler in the 1980s, it represents a new approach to the world, based on the creation of structures full of nanomolecules (78). With its expansion, nanotechnology found its way in medicine (79). Its expectations in neurosurgery are centred on nano-imaging, reconstruction, surgery and treatment, but most of all, on research (80, 81). In a similar way, biotechnology in the field of neurosurgery is applied in diagnosis, nanotechnology, neuroprotection, gene/cell therapy and research (82).

10. Psychosurgery

A new, different wave of expansion of neurosurgery was achieved by Moniz (83), who introduced the operation as therapy for mentally challenged people with the method named "lobotomy". His initiative was followed by the "pioneer of psychosurgery" (84), who actually operated six schizophrenic patients. Nowadays, psychosurgery is used for schizophrenic patients (85), anxiety disorders (86), drug addiction (87), multiple sclerosis (88), etc (Table 3. Psycho-DBS-surgery).

A controversial subcategory is deep brain stimulation (DBS), a therapy based on the electrical stimulation of the neurons. It is proposed for Parkinson's disease, movement disorders, aggressive behavior, epilepsy, trigeminal neuralgia, pain, Tourette syndrome and depression (89, 90); but from these, only dystonia, tremor and Parkinson's disease are approved by the Food and Drug Administration (Table 3).

DBS	Psychosurgery
- Parkinson's disease - Epilepsy - Tremor - Chronic pain - Trigeminal neuralgia - Depression - Aggressive behavior - Tourette syndrome - Alzheimer - Multiple sclerosis	- Drug addiction - Anxiety disorders - Schizophrenia - Multiple sclerosis

TABLE 3. Psycho-DBS-surgery

11. Head transplant

The idea of head transplantation is very old and it is getting closer to its realization. The whole idea is very futuristic, but it is accompanied of many complications and uncertainty (91). If this method works, however, it could be the door to another brain surgery universe.

SUMMARY

Neurosurgical history began in the very Ancient times BC, with Incas and Mayan.

Through the history of Ancient Egypt, Ancient Greece, Galen and Ancient Arabia, neurosurgical procedures were on the day planner. Later, when knowledge expanded, neurosurgical documents reported more innovative techniques and understandings, ensuring the management of even more pathologies. Cushing and his followers, however, established the peak, when neurosurgery took a new direction. Since then, concomitantly with the development of brain surgery, technology, education and skills have been also developing, making neurosurgery probably the most futuristic specialty that could ensure continuous decrease in mortality rate and an effective treatment of various brain and spinal cord pathologies and injuries. No matter what the future of neurosurgery will be, it is certain that neurosurgery will exist as long as people continue to live on Earth. ❑

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