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Historical aspects of microsurgical treatment of brain aneurysms

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Abstract

Based on the analysis of data on the development of surgical treatment of brain aneurysms, the authors identified the pre-surgical, early and late surgical stages and the microsurgical stage of development of the treatment of brain aneurysms. The microsurgical stage includes two basic areas — aneurysm microsurgery and reconstructive surgery of the vessel with aneurysm via its revascularisation. The paper seeks to identify key points in the development of microsurgical treatment of brain aneurysms, excluding reconstructive treatment, which requires a separate study. The development of the microsurgical stage is associated not only with the advent of the surgical microscope but also with the invention of corresponding instruments, microsurgical dissection techniques, and the creation and introduction of accessory equipment to improve the quality of the surgical procedure.

Keywords

history of medicine, brain aneurysm, subarachnoid haemorrhage, clipping, microneurosurgery

The history of surgical treatment of brain aneurysms can be split into several stages: pre-surgical, early and late surgical, and microsurgical (Bobinov et al., 2020). Based on the analysis of available data, the authors of this paper sought to identify key points in the development of microsurgical treatment of brain aneurysms. The study was conducted based on the available modern literature (starting from the mid-20th century). The data were analysed, and an attempt was made to systematise them and identify milestones of the microsurgical technique of treating brain aneurysms. A.F. Mavrogenis identified three key points critical for the development of microsurgery of brain aneurysms — the microscope, microinstruments, and microsutures (Mavrogenis et al., 2019). The study sought to identify pivotal aspects of the emergence and development of microsurgical treatment of brain aneurysms.

Invention and adoption of the surgical microscope

Giovanni Faber coined the term “microscope” in the 16th century. In 1660, Robert Hooke assembled a three-lens microscope that provided greater magnification than double-lens designs (Wing-Yee 2015; McNamara, Difilippantonio, Ried 2005). However, the invention of the

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microscope is associated with the name Antonie van Leeuwenhoek – a little-known linen merchant who invented the microscope while trying to create a device that could count the number of threads per square inch of linen fabric. He is considered the first to observe a living cell and blood circulation in capillaries under a microscope. He built over 500 microscopes, nine of which have survived to this day. Thanks to the discovery, observation and description of bacteria, protozoa, spermatozoa and blood cells, the inventor was accepted by the Royal Society of London (van Zuylen 1981).

Robert Hooke and Joseph Jackson Lister were able to modify the microscope at the turn of the 18th – 19th centuries. Hooke introduced coarse and fine adjustments and ball and socket joints. Lister was the first to use compound lenses made of more than one element, which significantly reduced spherical and chromatic aberrations (Lawson 2016; Howard 2013). In 1846, German engineer Carl Friedrich Zeiss opened the first microscope workshop in Jena (Louw, Sutherland, Schulder 2003). Soon after, he started working with physicist Ernst Karl Abbe, who developed new mathematical formulae and theories that revolutionised lens manufacturing (Shampo and Kyle, 1977).

The late 19th century was the time when microscopes gained broader acceptance in various industries and sciences. By the 1900s and 1920s, the microscope was already indispensable in every laboratory but had not yet conquered the operating theatre (Schultheiss and Denil, 2002).

Prescription lenses had been used in surgical operations since the 1860s. Later, surgeons started using single-lens glasses specifically for magnification, adjusting the magnifying power and focal ratio by moving the glasses along the nose (Roper-Hall 1967). In 1876, German doctor Edwin Theodor Saemisch was the first to use compound lenses for real magnification in surgery (Shanelec 1992).

The monocular microscope was first used in clinical surgery in 1921 by Swedish otologist Carl-Olof Nylen during an operation for chronic otitis media (Nylean 1954). In 1923, G. Holmgren and C. Zeiss made the first binocular instrument for otologic surgery and reported its utility in treating patients with otosclerosis (Holmgren 1923). According to S. Tamai, the history of the surgical microscope is the history of surgery for otosclerosis, which facilitated the development of the technology of manufacturing surgical microscopes to the current state (Tamai 1993). At the same time, another revolutionary discovery occurred in the diagnosis of brain aneurysms. Portuguese neurologist António Egaz Moniz[1] introduced the cerebral angiography technique into clinical practice in 1927 (Moniz, 1927). In 1934, he elaborated on his ideas. He pointed out the value of angiography in the diagnosis of intracerebral vascular malformations, describing the typical angiographic picture in the presence of a focus of effused blood in the temporal lobe of a patient with an aneurysm of the middle cerebral artery (Moniz 1934). Walter Edward Dandy, a student of Harvey Williams Cushing, is considered one of the founding fathers of the surgical treatment of brain aneurysms. Based on the results of this diagnostic technique, he performed the first successful clipping of an aneurysm of the internal carotid artery with a V-shaped clip in 1937. And in 1944, he laid out the basic principles of the surgical treatment of aneurysms, although the microscope would appear in the operating theatre much later (Dandy 1938, 1945).

H. Littmann later developed an optical design for variable magnification without changing the focal length. That design led to the development of the slit lamp for ophthalmology and the colposcope for gynaecologic surgery and was later used in the surgical microscope (Littmann 1950). In 1950, R.A. Perritt described the use of a binocular microscope in ophthalmic practice for the first time (Perritt 1950).

The history of how Zeiss, which had branches in both West (Zeiss Jena) and East (Zeiss Oberkochen) Germany, developed its surgical microscope is quite interesting. Jena began developing its first surgical microscope in 1949, led by Professor R. Albrecht. Testing began in the summer of 1950 at a university hospital of otolaryngology. VEB Optik Carl Zeiss Jena showcased a national and an international version of the surgical microscope at a trade fair in Leipzig in autumn 1952. Their mass production began in 1953. Zeiss Oberkochen's first surgical microscope was presented to the general public as a prototype of the

1 A.E. Moniz is a 1949 Nobel Prize winner in physiology or medicine "for his discovery of the therapeutic effect of leucotomy in certain mental illnesses".

OPMI-1 microscope, equipped with coaxial illumination, which is still in use today. The presentation was conducted by Dr. Horst Ludwig Wullstein at the 5th International Congress on Otorhinolaryngology, held in Amsterdam from 8 to 13 June 1953 (Gudziol, Gottschall, Luther 2017; House 1963).

In 1930, H. Cushing and L. Eisenhardt published a paper on intracranial tumour diagnosis by supravital technique. The paper explores the possibility of using a microscope in an operating theatre setting, not for performing surgical operations but for determining the tissue composition of the tumour. This marked the beginning of the era of intraoperative initial biopsy of neoplasms (Eisenhardt and Cushing 1930).

The use of the microscope in neurosurgical practice began in 1957 when T. Kurze removed a neurilemmoma of the seventh cranial nerve in a five-year-old patient at the University of Southern California (Kurze 1964). In surgery for aneurysms, the microscope was first used by R. Rand from the University of California in 1964 (Rand and Jannetta 1967). Charles Drake published the first-ever paper on this subject. In 1965, he described 14 surgical operations performed for aneurysms of the basilar artery, including using a surgical microscope (Drake 1965).

In 1966, J.L. Pool and R.P. Colton reported on their experience in the surgical treatment of cerebrovascular disease using a microscope. They presented 13 cases of clipping aneurysms and three cases of removing arteriovenous malformations, pointing out several advantages of the microscope, such as better visualisation of the aneurysm neck and arterial branches extending from it; more precise and correct application of the clip; reduced trauma during dissection; early identification of the source bleeding from vascular injury during dissection; and intraoperative assessment of vasospasm and its severity (Pool and Colton 1966). M.G. Yaşargil's team significantly contributed to the improvement of the surgical microscope. In collaboration with the Contraves Company in Zurich, it introduced electromagnetic brakes on each joint, ensuring the microscope's full mobility with perfect stability (Lovato et al. 2016).

The problem of intraoperative assessment of the radical extent of the cut-off of the aneurysm from the bloodstream and monitoring the patency of arterial branches after the application of clips has been explored since 1967 when William Howard Feindel et al. introduced the technology of intraoperative staining of cerebral vessels using a fluorescent contrast medium, an external camera and light filters (Feindel, Yamamoto, Hodge 1967).

In 1994, C. Wrobel et al. described the first use of indocyanine videoangiography during surgery for aneurysms (Wrobel et al. 1967). Also, Zeiss was the first manufacturer of a neurosurgical microscope with an integrated near-infrared lamp (800 nm), which allowed the visualisation of vessels stained with indocyanine green. In 2003, the work by A. Raabe et al., which described 14 cases of successful application of the intraoperative fluorescent angiography (IFA) technique for aneurysms and fistulas, led to a series of papers exploring the capabilities of the new technique. The IFA technique has been available to neurosurgeons in Russia since 2014, following the certification of the contrast medium (Éliava et al. 2015).

A.N. Konovalov was the first Russian neurosurgeon to use a surgical microscope in treating brain aneurysms. By 1973, he had already laid out the basic principles of microsurgery for brain aneurysms, described the peculiarities and advantages of using a microscope at the stages of approaching an aneurysm, and concluded that postoperative angiography was necessary to eliminate the risk of rebleeding from an aneurysm (Konovalov 1973).

Russian neurosurgeon Professor G.S. Tigliev was one of the first to use the surgical microscope and microsurgical technique. He paid special attention to maintaining the integrity of the venous bed when performing any surgical operation. From the mid-1970s, he actively developed and implemented the microsurgical operative technique for brain tumours, not only at the Polenov Neurosurgical Institute[2] but also at several other Russian neurosurgical institutions. One of G.S. Tigliev's most significant inventions was his proprietary surgical microscope. The last model – "Sasha-4" (MT-04) (Inventor's certificate No. 1835941 of 1992) – passed clinical trials at the

[2] From 2014 – a branch of the Almazov National Medical Research Centre.

Polenov Neurosurgical Institute and had a significant edge over foreign counterparts of that time. However, it was never mass-produced (Kondakov et al. 2004).

According to V.A. Khilko, in early 1971, the neurosurgical clinic of the Military Medical Academy named after S.M. Kirov in Leningrad started performing surgical operations on the central and peripheral nervous system using a surgical microscope manufactured by the Leningrad Krasnogvardeets Plant. In 1975, B.A. Samotokin published the first results of using microsurgery to treat brain aneurysms, pointing to a significant decrease in postoperative mortality (from 14% to 2%) (Khilko 1996).

Modern-day neurosurgical operations require frequent changing of instruments and the use of both hands, making it difficult to operate the microscope. Changing the angle of view, magnification, or focal length requires manual adjustment. One way of solving this problem was the Mari hand-free microscope operating device (Pitskhelauri et al. 2014), unveiled in 2006 by the Russian neurosurgeon and inventor D.I. Pitskhelauri, who developed and put it into practice. Other microscope models employ a foot pedal for this purpose. Freeing the surgeon's hands during the operation improved efficiency and sped up surgical procedures.

As a result, the surgical microscope has become an integral part of the treatment process in neurosurgical operations for cancer and vascular diseases of the central nervous system.

Microsurgical instruments, clips, accessory equipment

The gradual introduction of the microscope into neurosurgical practice drove the evolution of surgical techniques and instruments. Herbert Olivecrona modified Cushing's V-shaped clips, long used in aneurysm surgery. He added a spring-loaded opening mechanism, enabling the application and removal of the clip (Norlén and Olivecrona 1953). The first self-closing clips were invented in the 1960s by H. Schwartz and F. Mayfield. They were made of various alloys and stainless steel and were very popular in the 1960s and 1970s. M.G. Yaşargil introduced another model of aneurysm clips in the 1960s. His first clip was made of round wire and had transverse serrations. The second clip had a transverse ring designed to prevent incomplete clipping (Dujovny et al. 2010).

In October 1966, L.I. Malis introduced a bipolar coagulation device with miniature forceps for microvascular surgery, which remains the prime tool in vascular neurosurgery (Tamai 2009).

In 1967, T.M. Sundt and J.D. Nofzinger unveiled clip grafts for aneurysm surgery. Their application mechanism was slightly different from conventional clips since the graft had to completely encircle the vessel, thus acting as a prosthesis for the vessel wall from the outside. Excision of the aneurysm was recommended if necessary (Sundt and Nofzinger 1967). The idea behind such clips paved the way for reconstructive surgical treatment of aneurysms, although the clips never gained widespread use.

While performing surgery for aneurysms of the vertebrobasilar basin, Charles Drake encountered the problem of the involvement of the P1 segment of the posterior cerebral artery with the aneurysm sac or neck. To solve this problem, he developed the so-called Drake-Kees fenestrated clips, which enabled to preserve vessels involved in the aneurysm (Del Maestro 2000).

Between 1970 and 1980, the American Society for Testing and Materials assembled a special committee to study the quality of self-closing clips. Its work saw clips divided into temporary and permanent clips based on the assessment of their compressive force. The committee was also tasked with studying the biological compatibility of the clips, their magnetic properties, and evaluating their susceptibility to corrosion. Only two metals — high-quality cobalt-chromium alloy and titanium — were deemed suitable for making clips in terms of such characteristics as immobility in a magnetic field, the longevity of the structural shape and low susceptibility to corrosion (Tamai 2009).

The introduction of the intraoperative microscope required the modification of clips and clip holders to facilitate their positioning, application and removal. Clip holders were made considerably longer, and various modifications of their handles and controls emerged. Tools for applying temporary and permanent clips were distinguished by colour (Tamai 2009).

In the late 1970s, K. Sugita developed the first clip made of high-quality cobalt-chromium alloy, which had a protective bar to prevent incomplete clipping and an extra loop for better opening of the clip. It also had bayonet microinstruments that allowed performing manipulations without blocking the microscope's field of view (Tamai 2009). K. Sugita's other invention was the fixed retractor, which was first successfully used in aneurysm surgery in 1980 (Sugita et al. 1980). In 1975, he proposed using a nasopharyngeal mirror to provide a better view of the structures behind the aneurysm, determine whether the aneurysm is completely cut off from the bloodstream, and prevent the clipping of arterial branches passing behind the aneurysm sac (Sugita, Hirota, Tsugane 1975). Further development of this idea led to the introduction of the endoscopic assistance technique into neurosurgical practice.

In 1978, K. Sugita developed and implemented a system for complete fixation of the patient's head when performing neurosurgical operations, which not only greatly facilitated bone access but also enabled setting the desired head-turning angle for further operation. Also, retractors and other instruments used during surgery could now be mounted on a clamp (Sugita et al. 1978).

In 1990, German neurosurgeons G. Fisher and A. Perneczky were among the first to use an endoscope when clipping aneurysms. And further improvement of endoscopes, which became thinner and more flexible, enabled their use in the day-to-day practice of microsurgical clipping of brain aneurysms (Fischer, Oertel, Perneczky 2012).

In Russia, Yu.A. Shcherbuk studied the capabilities of neuroendoscopy, including microsurgery for brain aneurysms. Based on an analysis of his own data, he identified several advantages of the endoscopic video monitoring technique, such as better visualisation of the aneurysm before clipping, assessment of the involvement of arterial branches in the posterior wall of the aneurysm, and the ability to monitor the position of the clip (Samochernikh and Khachatryan 2015). In 2016, R.M. Kambiev continued the study of the use of endoscopy in surgery for brain aneurysms. He confirmed that this technique is most effective for posterior internal carotid artery aneurysms (the area of mouths of the posterior communicating and anterior choroid arteries) and aneurysms of the mouth of the posterior inferior cerebellar artery (Dzhindzhikhadze et al. 2018).

The quest for an alternative to intraoperative angiography led to the use of microvascular Doppler sonography during surgery. This technique was first demonstrated in 1976 by D. Cathignol (results of using a Doppler flowmeter on the aorta and pulmonary arteries after a lung transplant in a dog) (Cathignol et al. 1976). J.E. Bailes (1997) proposed using this diagnostic method in cerebrovascular surgery for treating brain aneurysms. In all cases, Doppler sonography results correlated with the angiography results. It was concluded that microvascular Doppler sonography could replace intraoperative and, in many cases postoperative, angiography (Bailes et al. 1997).

This technique has proven effective in Russia. The first results of the use of intraoperative Doppler sonography at the Department of Neurosurgery of the Military Medical Academy named after S.M. Kirov were published in 1996 in the "Actual problems of military neurosurgery" collection. According to the authors, the technique is indispensable for the rapid assessment of the patency of the main vessel carrying the aneurysm (Gaydar, Parfenov, Svistov 1996). In 2006, O.D. Shekhtman summarised the results of using contact Doppler ultrasound in surgery for brain aneurysms in his Ph.D. thesis at the N.N. Burdenko Neurosurgery Research Institute[3] under the guidance of Sh.Sh. Eliava (Eliava et al. 2006).

The idea of minimising the surgical approach using a 3D navigation technique based on spiral CT angiography data for more accurate projection craniotomy has also gained traction in the surgery of brain aneurysms. In 2003, R. Schmid-Elaesser published the first results of the projected use of a minimised burr hole, which enabled more limited dissection when approaching anterior circle of Willis aneurysms in 16 patients (Schmid-Elsaesser et al. 2003).

Microsurgical technique in neurosurgery

The use of the surgical microscope in neurosurgical practice has not only enabled more radi-

[3] Since 2017 – Federal State Autonomous Institution "N.N. Burdenko National Medical Research Center of Neurosurgery" of the Ministry of Health of the Russia Federation.

cal operations but has also significantly reduced intraoperative brain injury, such as retraction injury. S. Fisher in 1980 and M.G. Yaşargil in 1984 reported the significance of sufficient resection of the lesser wings of the sphenoid bone in reducing brain compression with spatulas when approaching aneurysms (Fisher, Kistler, Davis 1980; Yaşargil 1984).

Another major achievement was intraoperative short-term circulatory arrest using adenosine. The first case of its use in vascular neurosurgery was described in 1984 by A. Sollevi (Sollevi et al. 1984). Temporary proximal clipping presents an alternative method of stopping blood flow in the vessel with an aneurysm. J.L. Pool (1996) was the pioneer in this area. However, the safe duration of temporary clipping remained the subject of discussion for a long time. G.A. Asaturyan (2003) found the solution to this problem. He determined that preventive temporary clipping remained safe for no more than 20 minutes (Goroschenko et al. 2016).

The modern-day concept of treating brain aneurysms also developed thanks to the innovations of Finnish neurosurgeon J. Hernesniemi. He promoted the adenosine-induced cardioplegia technique and the use of a mouth-controlled joystick to operate the microscope. He developed his own approaches to brain aneurysms, distinguished by a small size of the burr hole and less trauma, thereby significantly shortening the duration of the operation (Lehecka, Laakso, Hernesniemi 2011). Professor J. Hernesniemi's methods are being used by Russian neurosurgeons. For instance, in 2018, A.I. Nikitin reported on 15 patients (two men, 13 women) who underwent microsurgical clipping of brain aneurysms using adenosine-induced cardioplegia between 2016 and 2017 at the Polenov Neurosurgical Institute. He claimed that this technique provides better relaxation of the aneurysm sac with asystole, coupled with or without temporary clipping, allowing for less traumatic and more radical clipping (Nikitin et al. 2018).

The intravascular blood aspiration technique proposed by H. Batjer et al. in 1990 demonstrated good results, including more radical microsurgical treatment of giant aneurysms (Batjer and Samson 1990). In 1996, this technique was successfully introduced into practice at the N.N. Burdenko Neurosurgery Research Institute by Sh.Sh. Eliava and is still used to this day (Eliava et al. 1996; *Mikrokhirurgicheskoe*… 2017).

In the second half of the 1990s, thanks to the development and adoption of microsurgical techniques, a more detailed study of the pathomorphology of aneurysmal disease, and advances in diagnostic equipment, the focus increasingly turned to the surgical treatment of brain aneurysms in the acute haemorrhage period. V.V. Lebedev and V.V. Krylov were heavily involved in this area. The scientific rationale and data supporting the effectiveness of early surgical intervention for ruptured arterial aneurysms are laid out in V.V. Krylov's thesis for his Doctor of Medical Science degree titled "Early surgical treatment of intracranial arterial aneurysms with vascular spasm and cerebral ischaemia",[4] defended in 1994. The same was also laid out in his monograph titled "Surgery for brain aneurysms in the acute haemorrhage period" (Lebedev et al. 1996).

Under the auspices of the Russian Society of Neurosurgeons, V.V. Krylov initiated and organised Russia's first-ever master classes and educational courses on microsurgery of brain aneurysms, which have been held every year since 2002. On 15 November 2012, the Ministry of Health of the Russian Federation issued order No. 928N "On the approval of the procedure for providing medical care to patients with acute cerebrovascular events". That order regulates the creation of regional vascular centres at multi-speciality hospitals to deliver specialised care to patients with acute cerebrovascular events. Under this order, new neurosurgical departments were opened, and old ones were upgraded. They have been equipped with surgical microscopes, surgical techniques are being improved, and new, minimally invasive approaches are being developed.

Professor V.P. Sakovich was actively involved in introducing the minimally invasive keyhole approach into surgical practice in Russia. He developed his own approach modifications, microsurgical techniques, and instruments, which are widely used in neurosurgical practice today (Sakovich, Kolotvinov, Lebedeva 2007).

The task of simultaneous surgical treatment of multiple brain aneurysms localised in different carotid territories was solved thanks to the contra-

[4] See: (*Khirurgiya*… 2011).

lateral approach, first proposed by M.G. Yaşargil in 1984. In Russia, V.V. Krylov was the first to conduct such an operation (Krylov, Tkachev, Dobrovolskiy 2002).

In conclusion, it may be noted that microsurgery is one of the primary ways of treating brain aneurysms in both the acute and cold periods of haemorrhage today. This type of surgery has several advantages, such as the capacity to visualise the aneurysm and the vessel carrying it, adequate monitoring of intraoperative bleeding, more radical cut-off of the aneurysm from the bloodstream, and a low recurrence rate in the postoperative period. Microsurgical treatment of various aneurysms (fusiform, giant, serpentine) comes with certain challenges when using standard approaches due to the anatomical features of the aneurysms. To a great extent, this problem can be solved by a separate area of microsurgery, which includes reconstructive procedures with revascularisation of the affected segment of the artery. However, this area calls for a separate discussion.

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