Review paper

From magnifying glass to operative microscope – the past and the present of microsurgery

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The modern computer-assisted microscope, being a hallmark of microsurgery, has become a standard piece of equipment in the operating theatre. Its introduction enabled visualisation of fine anatomical structures, obscure to the unaided eye, and revolutionised many surgical specialties, such as neurological, ophthalmological, or vascular. These astounding achievements have been the culmination of a century of constant progress in optical engineering and microsurgery, since 1921, when a microscope was first used during surgery. Long before surgery, pathology adopted microscopes, and they have become its most prominent diagnostic tools.
We traced the evolution of this important invention and discussed its present status and future prospects.

Key words: neurosurgery, microscope, history, operative.

The microscope is an optical instrument, mostly based on a combination of lenses, which produces a visual image of miniature objects. The origin of this word comes from Ancient Greek. It is composed from two words: micros (μικρός), which means small, and skopein (σκοπέω), which means to look or to see [1]. The first historical proof of the magnifying device was not recorded until the 10th century by an Arabian scholar Alhazen [4]. It was based on a convex lens forming a magnified image. The first spectacles were invented in the 13th century by Salvino D'Armato in Italy. He presented the first widespread practical use of magnification in society as an aid for old people with weak sight [5].

In 1590 two Dutch opticians (spectacle makers), father and son – Hans and Zacharias Janssen, took a step further. They created simple but resourceful combination of two lenses inside a tube, which is considered to be an archetype of the telescope and microscope. Independently, Italian scientist Galileo Galilei (1564-1642) developed the same invention by inverting his previous *tubum opticum*, or telescope, allowing him to see "flies as large as hens". Furthermore, he improved it by implementing a focusing device. A quarter of a century later Giovanni Faber (1574-1629) introduced the term "microscope". In 1660, Robert Hooke used three lenses in a compound microscope to achieve higher magnification than that possible in earlier two-lens designs [6, 7].

Perhaps the name most closely associated with the early microscope is that of Anton von Leeuwenhoek. He was originally an obscure linen draper who

invented a microscope while trying to build a device that could help him count the number of threads per square inch of material. It was a simple device, but it enabled him to magnify objects up to 270 times. Leeuwenhoek is considered to be the first person to witness a live cell under the microscope as well as the circulation of blood in tiny capillaries. He constructed more than 500 microscopes, nine of which have lasted until today. Thanks to the discovery, observation, and description of bacteria, protozoa, sperm, and blood cells, Leeuwenhoek earned membership in the prestigious Royal Society of London [8].

Between the 18th and 19th century Robert Hooke and Joseph Jackson Lister (father of the renown surgeon and founder of antiseptics Joseph Lister) made some technical advances that significantly improved microscopes. Hooke introduced coarse and fine adjustments and ball and socket joints. Lister, a wine merchant and amateur microscopist, was the first to use compound lenses from more than one element, significantly reducing spherical and chromatic aberrations [9, 10]. Lister's law of aplanatic foci remained the underlying principle of microscopic science. He wrote a paper in 1843, entitled 'On the Limit to Defining Power in Vision with the Unassisted Eye, the Telescope and the Microscope', which was presented by his son John Lister to the Royal Microscopical Society, and influenced many of the later discoveries [9, 10]. In 1846, a German mechanist Carl Zeiss opened the first microscope workshop in Jena, Germany [11]. Soon thereafter he started to work with physicist Ernst Abbe, who derived new mathematical formulas and theories that revolutionised lens making [12].

This invention is thought to be the beginning of mass production of high-quality microscopes. In 1893 Zeiss introduced the idea of the binocular telescope.

The end of the 19th century was a time when microscopes were widely recognised in various branches of industry and science. In the early decades of the 20th century the microscope was already an integral part of every laboratory, but it had not reached the operating room yet [13].

In 1921, Swedish otologist and tennis player, Carl Olof Nylen, built the world's first surgical microscope, which was used for a chronic otitis media case [14]. The attachment of a light source was a subsequent upgrade of the tool, and finally, a year later, Swedish otologists introduced the first binocular microscope.

When discussing the role of the microscope in the development of medicine, it seems obligatory to mention its crucial role in pathology. The overwhelming majority of pathology diagnostics is centred around the usage of this single invention, hence it might be difficult to imagine how pathologists had functioned prior to its introduction. As pathology originates from anatomy and surgery, through the centuries it was based on gross descriptions of lesions; nevertheless, it was not until the 19th century that anatomical pathology emerged as an independent discipline.

The first step leading to the development of medicine and anatomical pathology itself was the acknowledgment of the importance of autopsies as a method of exploring the human body and diseases. The progress occurred in the 16th century with Andreas Vesalius (1514-1564) as the most significant contributor of the era of autopsy and anatomy. In the 17th and 18th century autopsies were popularised, hence expanding the number of documented descriptions of pathological organ changes due to diseases. This process led to Giovanni Batista Morgagni (1682-1771) publishing his works, most importantly *De Sedibus et Causis Morborum per Anatomen Indagatis* (1761) [15]. At the beginning of the 19th century dissecting rooms became a common part of larger hospitals, and anatomical pathology became a significant part of clinical diagnostics. Finally, in the second half of the 19th century, the works of Rudolf Virchow (1821-1902) created the basis of modern pathology as we know it, by introducing his views in *Die Cellularpathologie* (1858). He implied that the cells seen as a manifestation of diseases, especially neoplasms, were actually transformed from the original organ cells due to the pathophysiological processes taking place in them, rather than being separate entities. Virchow was the first to suggest a systemic microscopic studies of pathologic tissues [15, 16]. Despite the fact that Rudolf Virchow is considered the father of microscopic pathology, examining tissues and diagnosing the changes in them began a long time before him. There are several documented cases of investigating pathologically changed tissues with the use of a microscope, e.g. the analysis of samples taken during the autopsy of pope Innocent XII performed in 1700 [17].

Another interesting example might be the procedure performed by Ludwig von Hammen (1651-1689) in 1678 in Gdansk, documented in his correspondence with Johann Nicolaus Pechlin (1646-1706). Von Hammen removed a tumour from a man with impaired urination, and after the surgery he used a microscope to determine the nature of this lesion. In the correspondence with Pechlin, he described his microscopic findings as a glandular tumour of mixed composition – with tissue built of tiny fibres and deposits resembling dark salt crystals. This was, possibly, one of the first post-surgical microscopic tissue examinations ever performed; von Hammen L *De herniis dissertatio Academica. Accedunt de Crocodilo ac vesicae mendaci calculo epistolae et responsiones ad Magnificum atque Excellentissimum D. Carol. Drelincurtium*

Medicum Regium & Professorem Primarium Lugd. in Bat. longè Celeberrimum. Apud Cornelium Boutesteyn, Lugduni Batavorum 1681 [18].

From what is known, the first person to extensively use the microscope for observing human tissues was the physiologist Marcello Malpighi (1628-1694). Nevertheless, his innovative histological research involved only normal tissues. Marie Francois Xavier Bichat (1771-1802) can be considered the father of "histology". He managed to distinguish 21 types of tissues, but without the use of a microscope, instead using only simple physicochemical methods.

The most significant successor to Bichat's idea was Thomas Hodgkin (1798-1866) from Britain. He used a microscope to examine tissues obtained from autopsies. Hodgkin cooperated with the above-mentioned Joseph Lister (1786-1869) and expressed high hopes for the future use of this device in medicine [15].

Initially, for many years, microscopic pathological examinations were performed on frozen autopsy tissue sections only. The analysis of sections from living patients was not practiced. At the end of the 19th century microscopic histological assessment of diseased tissue samples taken during operations was performed mainly by surgeons and other clinicians. One of the precursors of surgical biopsy was the great contributor to microscopic diagnostics in gynaecology Carl Arnold Ruge (1846-1926), who introduced it in the 1870s together with Johann Veit (1852-1917). A great development in surgical biopsy was in the form of frozen section procedure - some of the earliest reports of this method involve the work of Thomas Cullen (1868-1953) and William Welch (1850-1934) – both from the Johns Hopkins Hospital in Baltimore. Joseph Bloodgood (1867-1935), also from JHH, was one of the first surgeons to utilise this method for intraoperative microscopic examinations [19].

In the beginning, the histopathological specimens were unstained. Haematoxylin and eosin were introduced in 1863. Later, in the years 1885-1892, several special stains showing tissue and cellular details were discovered: Ziehl-Nielsen, Gram, Congo, and van Gieson. The first person to embed and preserve tissue samples in paraffin for better and delayed histotechnology (as it is used nowadays) in 1869 was Edwin Klebs. Formalin became a widely used fixative in 1893 [15].

The method was later adopted and modified by the father of neurosurgery, Harvey Cushing (1869-1939), who used smears of collected tissue stained according to Sabin for intraoperative diagnosis of brain and spine tumours [20] (Fig. 1). This would not have been possible if Cushing, together with his co-worker, Percival Bailey (1892-1973), had not created the first classification of gliomas in 1926 [21] (Fig. 2).

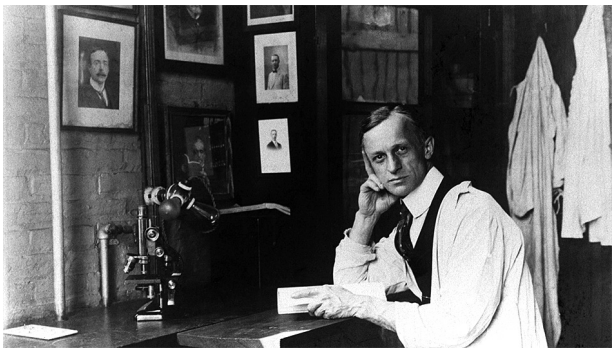

Fig. 1. Harvey Cushing (1907). Photo credit: Yale University, Harvey Cushing/John Hay Whitney Medical Library

Fig. 2. Percival Bailey (1932). Photo credit: Yale University, Harvey Cushing/John Hay Whitney Medical Library

Before long, the technique was utilised by neurosurgeons in other countries, including Adam Kunicki (1903-1989) and Brunon Imieliński in Poland [22, 23] (Figs. 3, 4).

Currently, light microscopes are the heart of modern histopathology, combined with a wide array of special stains and immunohistochemistry methods. What is more, it is not uncommon to use other types of microscopy in pathology, i.e. phase-contrast, fluorescent, or electron microscopes. The value of microscopic diagnoses has become a vital part of the therapeutic process in many specialties, especially with the development of fast and efficient methods of preparing specimens for both regular and intraoperative histopathological examination.

Despite the fact that first photographic images were performed as early as in 1839 (owing to the improvements implemented by Lister, Abbe, and Leitz), it seems that microphotography might enter its best period in the present due to the development of digital imaging (Fig. 5). In recent years there has been a steady improvement of the quality

Fig. 3. Adam Kunicki (1970s). Photo credit: Medical University of Warsaw

and availability of a variety of tissue section scanners and digital cameras dedicated for light microscopes. Currently digital images of histopathological specimens have reached a level of resolution and accuracy unimaginable in the past. Taking into consideration the rapid development of technologies for storing and transferring digital data, one might expect that in the near future virtual microscopy can become a common solution, offering fast access to high quality microscopic images, over virtually unlimited distances, as well as using almost no storage space in opposition to classic glass plate specimen archives. It is, however, an object of much debate when or whether virtual microscopy can totally replace traditional light microscopy [24].

In the 1950s, several technical developments allowed microsurgery to blossom [25]. Hans Littmann had invented an optical construction for changing magnification without changing focal length. Microscopes started to be used in every field that required advanced precision – mostly in ear, throat, and eye surgery [13].

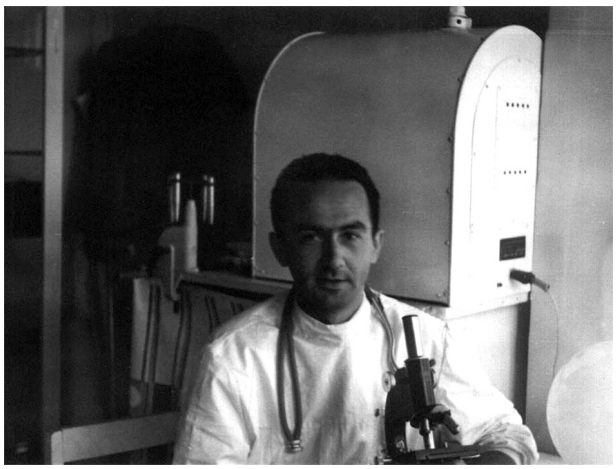

Fig. 4. Brunon L. Imieliński (1970s). Photo credit: Department of Neurosurgery, Copernicus Hospital in Gdansk

However, the original surgical microscopes had several disadvantages. They were attached to the operator's head, which restrained stability, and they had a limited vision area of around 6-12 mm.

In 1953 Zeiss began the first serial production of an operating microscope prototype called the ZeissOpMi 1 (Zeiss Operating Microscope Number One) [26]. The year 1957 was a breakthrough. At the University of California, American neurosurgeon Theodore Kurze performed first microscope-assisted neurosurgery – he removed a neurilemoma in the cranial nerve VII from a five-year-old patient, and so the era of microneurosurgery had begun [27].

Vascular microsurgery is another branch of medicine that owes its significant development to microscopy [28]. In 1961 J. Lawrence Pool at the Neurological Institute in New York, published the first report of successful use of a microscope in intracranial aneurysm surgery [29].

M.G. Yasargil in Zurich and R.M.P. Donaghy in the United States successfully performed the world's first superficial temporal artery – middle cerebral artery bypass in a human [30]. The anastomoses in both patients remained open for many years. During the subsequent five years, Yasargil's group in Zurich in conjunction with the Contraves Company devised a microscope with electromagnetic brakes at each joint, permitting full mobility with perfect stability [27, 31].

Present day

Operating microscopes have improved remarkably since their first entrance to the operating theatre. Nowadays, the high-tech operating microscope has a camera attached, allowing all the surgical procedures to be recorded in high definition (Fig. 6). Controls for releasing the electromagnetic brakes and adjusting magnification can either be placed on handles or on a pedal [32]. What is more, it is possible for two assistants to obtain the same surgical field as the primary operator. With appropriate attachments, surgeon can visualise structures that are difficult to see with the naked eye. Module FL-400 provides blue light illumination, which exposes malignant glioma tissue in patients who have been given 5-aminolevulinic acid orally [33]. The FL-800 module offers intraoperative angiography by detecting intravenously injected ICG (Indocyanine Green) and shows the images on a monitor [34]. Another useful invention is neuronavigation – a set of computer-assisted technologies that accurately project computed tomography (CT) or magnetic resonance imaging (MRI) data into the operative field and allow the surgeon to perform the operation on pre-defined anatomical landmarks based on pre-operative data planning to approach deep-seated pathologies in cranial surgery [35-37] (Fig. 7).

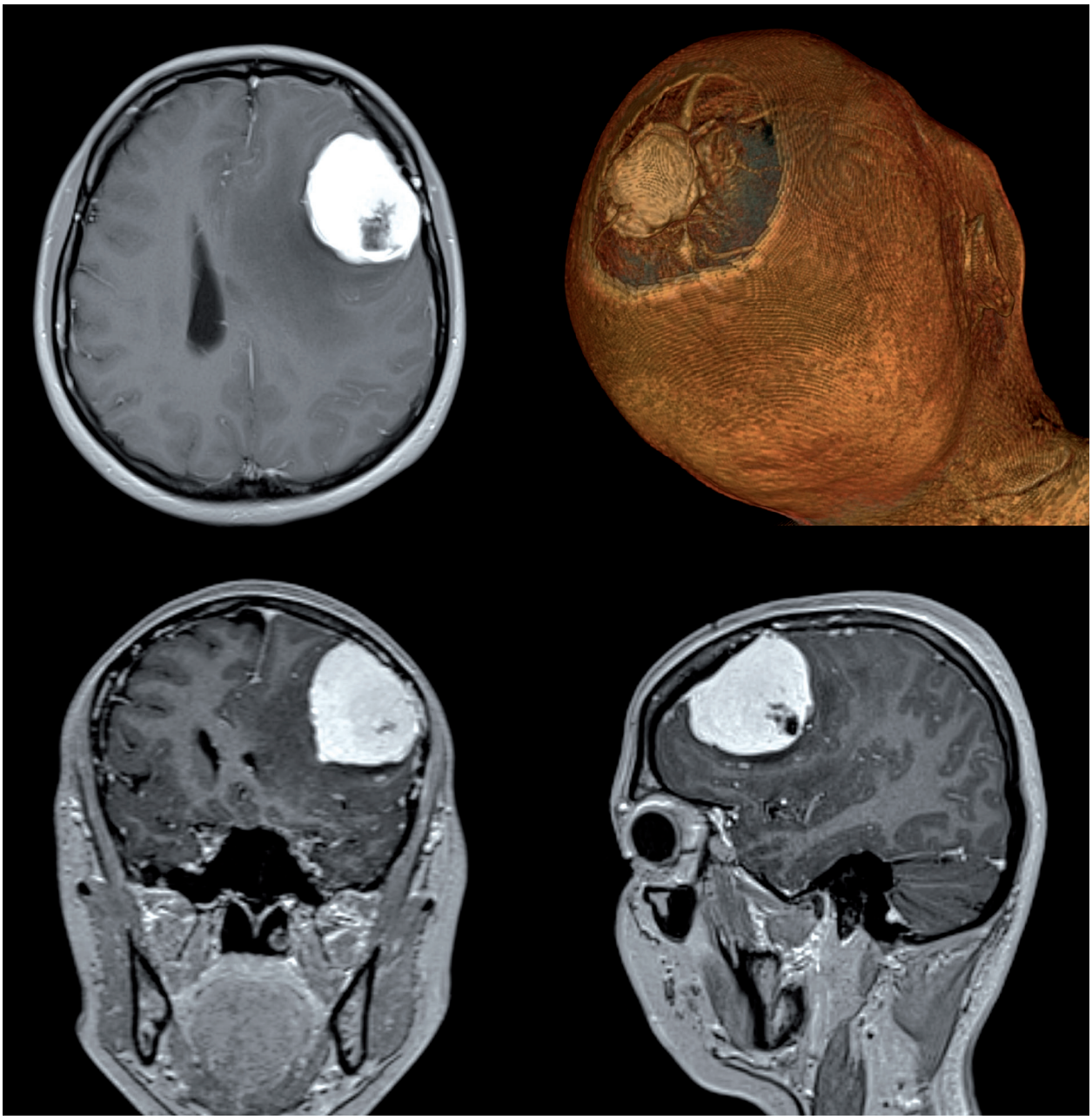

Fig. 5. MRI of left frontoparietal meningioma with peritumoral oedema. Photo credit: Department of Neurosurgery, Copernicus Hospital in Gdansk

The latest alternative that has been proposed to the operating microscope is an exoscope. It is a high-definition video telescope operating monitor system to perform microsurgery. The exoscope enables surgeons to complete the operation by visualising magnified images on a display. A wide field of view and deep focus are major advantages of such equipment. It minimises the need for repositioning and refocusing during the procedure, asserting thereby more comfort and stability [38, 39, 40]. However, limited magnification is a weak point of this device. The procedures are performed under 2D motion images. Nevertheless, stereoscopic vision is required to improve hand and eye coordination for high precision works. Facing this disadvantage, the Karl Storz company created new operating microscope – the Vitom 3D – that provides 3D visualisation for microsurgery and open surgery with high-resolution digital images and a stereoscopic visual field. The Vitom 3D consists of an operating telescope, a holding arm, a camera system, a light source, a control unit, and a 3D Monitor [41, 42].

The development of the operating microscope has enabled further progress in microsurgery. It created the possibility of advancing minimally invasive surgical techniques. A large number of lesions previously considered to be non-surgical have become available

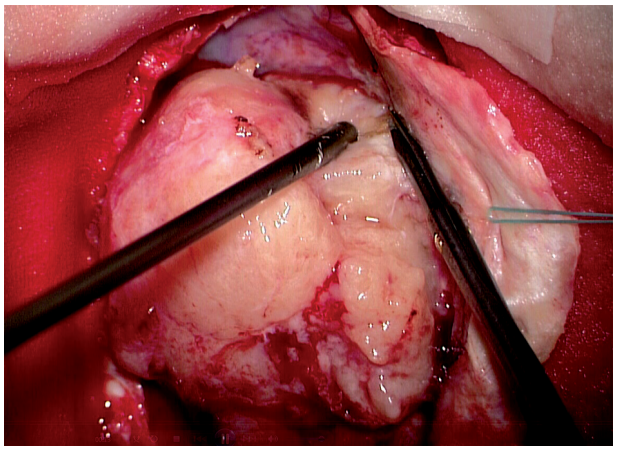

Fig. 6. Meningioma – intraoperative microscope view (magnification 6×). Photo credit: Department of Neurosurgery, Copernicus Hospital in Gdansk

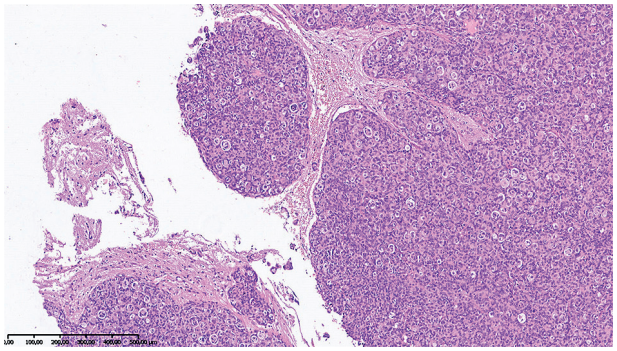

Fig. 8. Meningioma grade II with brain invasion – light microscope view, HE stain (100×). Photo credit: Department of Pathomorphology, Copernicus Hospital in Gdansk

Fig. 7. Neurosurgeon during spinal microscopic operation assisted by intraoperative neurophysiologic monitoring. Photo credit: Department of Neurosurgery, Copernicus Hospital in Gdansk

for treatment. The future development of technologies such as surgical instrument tracking auto-focus will thus have the potential to significantly shorten the duration and enhance the quality of the surgery [42].

Despite the passage of time, almost 500 years after Zacharias and Hans Janssen aligned two lenses, the microscope functions as a vital tool for both pathologists and surgeons, being an indispensable tool for diagnosis as well as treatment of patients.

The authors declare no conflict of interest.

References

1. Kalderon A. The evolution of microscope design from its invention to the present days. Am J Surg Pathol 1983; 7: 95-102.
2. Uluç K, Kujoth GC, Başkaya MK. Operating microscopes: past, present, and future. Neurosurg Focus 2009; 27: E4.
3. Singh S. Fundamentals of optical engineering. Discovery Publishing House, New Delhi 2009; 4-13.
4. Shampo MA, Kyle RA. Alhazen (iln-al Haitham, Abu ibn Al Haithum, or Iben Al Haithum). JAMA 1976; 235: 1017.
5. Rubin ML. Spectacles: past, present, and future. Surv Ophthalmol 1986; 30: 321-327.
6. Wing-Yee C. Evolution and clinical application of microsurgery. BMC Proc 2015; 9: A53.
7. McNamara G, Difilippantonio MJ, Ried T. Microscopy and Image Analysis. Curr Protoc Hum Genet 2005; 46: 1-34.
8. van Zuylen J. The microscopes of Antoni van Leeuwenhoek. J Microsc 1981; 121: 309-328.
9. Lawson I. Crafting the microworld: how Robert Hooke constructed knowledge about small things. Notes Rec R Soc Lond 2015; 70: 23-44.
10. Howard ER. Joseph Lister: his contributions to early experimental physiology. Notes Rec R Soc Lond 2013; 67: 191-198.
11. Louw DF, Sutherland GR, Schulder M. From microscopic to astronomic, the legacy of Carl Zeiss. Neurosurgery 2003; 52: 668-674; discussion 672-674.
12. Shampo MA, Kyle RA. Ernst Abbe (1840-1905). JAMA 1977; 237: 2198.
13. Schultheiss D, Denil J. History of the microscope and development of microsurgery: a revolution for reproductive tract surgery. Andrologia 2002; 34: 234-41.
14. Dohlman GF. Carl Olof Nylén and the birth of the otomicroscope and microsurgery. Arch Otolaryngol Chic Ill; 90: 813-817.
15. van den Tweel JG, Taylor CR. A brief history of pathology: Preface to a forthcoming series that highlights milestones

in the evolution of pathology as a discipline. Virchows Arch 2010; 457: 3-10.
16. Ribatti D. An historical note on the cell theory. Exp Cell Res 2018; 364: 1-4.
17. Ria MA, Borghi L, Pagni F. The first recorded use of microscopy in medicine: Pope Innocent XII's autopsy report. Lancet 2016; 388: 559.
18. Szarszewski A, Gulczyński J. The History of calculus mendax and the following surgery on the prostate. Prostate 2014; 74: 1465-1470.
19. Lechago J. The frozen Section: Pathology in the Trenches. Archives of Pathology & Laboratory Medicine 2005; 129: 1529-1531.
20. Eisenhardt L, Cushing H. Diagnosis of intracranial tumors by supravital technique. Am J Path 1930; 541-552.
21. Bailey P, Cushing H. A classification of the tumours of the glioma group on a histogenetic basis, with a correlated study of prognosis. Medium 8vo. Pp. 175, with 108 illustrations. J. B. Lippincott Company, Philadelphia, London, and Montreal 1926.
22. Imieliński BL. Zależność występowania glejaków śródczaszkowych od różnych czynników środowiskowych i biologicznych. Rozprawa habilitacyjna. Akademia Medyczna w Gdańsku, Gdańsk 1973.
23. Kunicki A, Stefanicka-Wiechowa A. Phase-contrast microscopy in the diagnosis of central nervous system tumors. Pol Med Sci Hist Bull 1962; 5: 23-28.
24. Taylor CR. From Microscopy to whole slide digital images: a century and a half of image analysis. Appl Immunohistochem Mol Morphol 2011; 19: 491-493.
25. Hamberger CA. Gunnar Holmgren (1875-1954). Arch Otolaryngol Chic Ill 1960 1968; 87: 214-218.
26. Gudziol H, Gottschall R, Luther E. The Development of First Operating Microscopes from Zeiss Jena and Oberkochen to Series Production. Laryngorhinootologie 2017; 96: 27-34.
27. Kriss TC, Kriss VM. History of the operating microscope: from magnifying glass to microneurosurgery. Neurosurgery 1998; 42: 899-907; discussion 907-908.
28. Jacobson J, Suarez E. Microsurgery in anastomosis of small vessels. Surg Forum 1960; 11: 243-245.
29. Komotar RJ, Zacharia BE, Mocco J, Connolly ES. Controversies in the surgical treatment of ruptured intracranial aneurysms: the First Annual J. Lawrence Pool Memorial Research Symposium – controversies in the management of cerebral aneurysms. Neurosurgery 2008; 62: 396-407; discussion 405-407.
30. Newell DW. Superficial Temporal Artery to Middle Cerebral Artery Bypass. Skull Base 2005; 15: 133-141.
31. Lovato RM, Vitorino Araujo JL, de Paula Guirado VM, et al. The Legacy of Yasargil: the Father of Modern Neurosurgery. Indian J Surg 2016; 78: 77-78.
32. Orringer DA, Golby A, Jolesz F. Neuronavigation in the surgical management of brain tumors: current and future trends. Expert Rev Med Devices 2012; 9: 491-500.
33. Hadjipanayis CG, Widhalm G, Stummer W. What is the Surgical Benefit of Utilizing 5-Aminolevulinic Acid for Fluorescence-Guided Surgery of Malignant Gliomas? Neurosurgery 2015; 77: 663-673.
34. Gioux S, Choi HS, Frangioni JV. Image-guided surgery using invisible near-infrared light: fundamentals of clinical translation. Mol Imaging 2010; 9: 237-255.
35. Li F-Y, Chen X-L, Xu B-N. Intraoperative high-field magnetic resonance imaging, multimodal neuronavigation, and intraoperative electrophysiological monitoring-guided surgery for treating supratentorial cavernomas. Chronic Dis Transl Med 2016; 2: 181-188.
36. Oppenlander ME, Chowdhry SA, Merkl B, et al. Robotic autopositioning of the operating microscope. Neurosurgery 2014; 10 Suppl 2: 214-219; discussion 219.
37. Ganslandt O, Behari S, Gralla J, et al. Neuronavigation: concept, techniques and applications. Neurol India 2002; 50: 244-255.
38. Mamelak AN, Danielpour M, Black KL, et al. A high-definition exoscope system for neurosurgery and other microsurgical disciplines: preliminary report. Surg Innov 2008; 15: 38-46.
39. Nishiyama K. From Exoscope into the Next Generation. J Korean Neurosurg Soc 2017; 60: 289-293.
40. Piquer J, Llácer JL, Rovira V, et al. Fluorescence-Guided Surgery and Biopsy in Gliomas with an Exoscope System. Biomed Res Int 2014; 2014.
41. Sack J, Steinberg JA, Rennert RC, et al. Initial Experience Using a High-Definition 3-Dimensional Exoscope System for Microneurosurgery. Oper Neurosurg Hagerstown Md 2018; 14: 395-401.
42. Beez T, Munoz-Bendix C, Beseoglu K, et al. First Clinical Applications of a High-Definition Three-Dimensional Exoscope in Pediatric Neurosurgery. Cureus 2018; 10: e2108.

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