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 Arab-Iran 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 which was 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 Anatomam 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 I. De herniis dissertatio Academica. Accedunt de Crocodilo ac vesicae mendaci calculo epistole et responsiones ad Magnificam atque Excellentissimum D. Carol. Dreincartium

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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 François 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).

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.
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].

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 Zeiss OpMi 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).
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.
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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.

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