The application of an endoscope to treat hydrocephalus is an old technique having its beginnings in the early 20th century. Sir Walter Dandy and other cranial surgeons started to apply endoscopic surgical techniques to treat hydrocephalus with cauterization or removal of the choroid plexus. Because of very high morbidity and mortality rates and the simultaneous development of the first good-quality systems for ventriculoperitoneal shunting, neuroendoscopic applications were abandoned in the 1950s and 1960s. Cerebrospinal fluid shunting became the preferred procedure to treat hydrocephalus. However, with further technical development of the endoscopic instruments and the increasing awareness of long-term complications with various shunt systems, neuroendoscopy regained interest in the 1980s and early 1990s. In this paper, we discuss the almost simultaneous development of neuroendoscopic techniques in Europe from the 1980s until today. Particular reference is made to the step-by-step evolution of the various techniques and systems and the specific considerations behind them.

Technical Development of Endoscopes

Present neuroendoscopy would not have been possible without the substantial improvements in the optical quality of the endoscopes. The major breakthrough in endoscope technology goes back to the work and inventions of Harold Horace Hopkins (1918–1994), a professor of physics at the University of Reading, United Kingdom. He would probably have remained only a recognized physicist if he had not been approached by the consultant physician, complained about the poor image quality and rigidity of available endoscopes. Encouraged by the subsequent discussion, Hopkins developed the idea of using glass fibers for image transmission. In 1951 he assembled a bundle of glass fibers with a higher refractive index of the core than of the cladded coat to increase the total reflection and improve transport of the optical image over a longer distance. By 1953 he and his research fellow Narinder Singh Kapany produced a bundle of fibers with precisely the same order at the proximal and distal ends, leading to a coherent image. They published their results in *Nature* in 1954. In the same volume and on the same page Abrahm van Heel, a Dutch scientist, reported his experience, preferring plastic material in-
of this technology into the medical field. The term “cold light” was originally used for the illumination of film and photoendoscopes of French production, which were distributed by Karl Storz since 1952. Storz used this term to label the new halogen light source technology of his endoscopes. Since 1969, rod lens endoscopes have also been produced by Richard Wolf in Knittlingen, Germany. Today, xenon light sources are used instead of halogen, whose effective power was limited to 250 W and caused a yellow image quality. With today’s xenon light (which is also used for microscope illumination), far higher light energy of almost sunlight quality is achieved. However, the light is not really “cold,” as heat (infrared portion of radiation) is also transmitted through the fiber lines, so that the hot tip of an endoscope has to be considered potentially dangerous—in neuroendoscopy in the ventricles, therefore, irrigation is recommended even in the absence of bleeding.

The technical development of rigid rod-lens endoscopes combined with a cold light source was completed by the introduction of video cameras for imaging to replace direct observation by the surgeon looking through the endoscope. First attempts were made in 1956 when television cameras with the option of videotaping were used. However, the use of articulated arms to connect the glass lenses to the large cathode ray television cameras was difficult in a sterile setting and prevented routine use. Finally, light, miniature electronic cameras equipped with charge-coupled devices (CCDs) transforming the light signal to a digital signal contributed essentially to the miniaturization of the cameras, which could be directly connected to the endoscope oculars with a sterile cover (Fig. 1). The image quality improved to > 400 lines at the end of the 1980s, and there was a high-resolution monitor screen with the option to store and later review the endoscopic data—initially by videotaping, later by digital recording. This setup, originally assembled for urology, diagnostic bronchoscopy, gastroscopy, arthroscopy, and minimally invasive abdominal surgery, was commercially available at the end of the 1980s. Later, this version of endoscopes and this setup were used by various neurosurgeons for their first interventions and were subsequently adapted for neurosurgical requirements. Today, the miniaturized cameras are available in full high-definition resolution with 3-CCD quality and can be fully sterilized.

**Influence From Other Medical Disciplines**

Endoscopic instruments were neither developed for neurosurgeons nor primarily used by them. In 1904 the urologist Victor L’Espinasse fulgurated the choroid plexuses in 2 infants by using a cystoscope, and he presented data on these cases at a local medical meeting in 1910. In 1939 L. E. Davis described this pioneering work in his book on hydrocephalus and spina bifida. The lack of interest from neurosurgeons on this technique remained over the subsequent decades. Of the practitioners among the various disciplines, neurosurgeons were among the last to systematically apply this technique. Urologists, gastroenterologists, and general surgeons in the US intro-
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In 1976 these disciplines organized themselves as a “surgical study group on endoscopy and ultrasound.” In 1984 the surgeon John E. A. Wickham coined the term “minimally invasive surgery.” He published his surgical philosophy in the British Medical Bulletin in 1986. Later the Society of American Gastrointestinal Surgeons was formed, and its first journal, Surgical Endoscopy, was founded in 1987. The first world congress on surgical endoscopy took place in 1988.

Toward Endoscopy in Neurosurgery

For the application of endoscopes in neurosurgery, 3 presuppositions had to be fulfilled: the endoscopes had to be applicable in the brain, there had to be a demand for the technology, and the endoscopic technique had to be at least equal or better than the established surgical technique. For optical reasons, the application of endoscopes is restricted to preformed anatomical cavities. In neurosurgery, these spaces were the ventricles and the subarachnoid space in open neurosurgical approaches. Furthermore, given the risks of complications associated with changes in surgical technology, there had to be a demand for a change in the surgical concept if a new technology were to be introduced.

In the late 1980s, the handling of hydrocephalus constituted a neurosurgical problem because shunt infections and dysfunctions made frequent revisions necessary. Patients with a disease origin within the ventricles were considered to be ideal candidates for a neuroendoscopic approach. The question was whether an ETV performed at the floor of the third ventricle, directly connecting the ventricles with the subarachnoid space and bypassing the posterior fossa, could avoid shunting in obstructive hydrocephalus. This technique was already known from the work of Dandy, Mixter, and Scarff at the very beginning of neurosurgery in the 20th century. Particularly because of a very high complication rate and a high mortality rate, the ETV technique was given up after the introduction of valve-based shunt systems to the clinical routine. It was assumed that with the modern qualitatively advanced Hopkins endoscopes, ETV could be performed under visual control more safely than in the past. Moreover, it was supposed that with ETV, a permanent treatment without the implantation of foreign material could be achieved, regulating the production and resorption of CSF physiologically and regulating them better than with any valve-based system despite the great progress in this field. In Europe, the ETV attracted clinical interest after the article by H. Griffith in 1986, who used the Storz Hopkins optics having a 4-mm diameter and 18-cm length combined with an attached mini-video camera for ventriculoscopy. Biopsies of intraventricular tumors and the treatment of intraventricular cysts, including colloid cysts, were other indications that seemed to be endoscopically manageable with a less invasive approach than open microsurgical removal. For a comprehensive survey on the history and technique of ETV refer to Hellwig et al.

Development of Neuroendoscopy in the Ventricles From 1960 to 1990

In the 1960s and 1970s, there were only sporadic reports on the utility of endoscopic techniques in neurosurgery. By 1968 Guiot et al. already used an endoscope for endocranial purposes. Almost simultaneously, Fukushima performed ventriculoscopies with a 3-mm-diameter flexible fibroscope for the diagnosis of tumors in the third ventricle in unclear cases in the pre-CT era. In 1973 he developed a special needle endoscope with the Olympus Company for the biopsy of intraventricular tumors. In 1977 Griffith published his preliminary clinical experience with coagulation of the choroid plexus for the treatment of hydrocephalus by using the Hopkins endoscope. Shortly thereafter in 1978, Vries described the first 5 patients with occulsive hydrocephalus who had been treated using an endoscope-controlled third ventriculostomy via a freehand technique. In 1986 Kelly and colleagues started to perform third ventriculostomy for occulsive hydrocephalus by employing a CT-based stereotactic technique after calculating the stereotactic tra-
jectory through the foramen of Monro to the floor of the third ventricle. They used the endoscope while advancing the canula into the lateral ventricle through the foramen of Monro into the third ventricle, and for visual control of the floor of the third ventricle and the subarachnoid space after perforation. The perforation itself was performed with the leukotome without direct visual control. In France, ventriculostomy had a long tradition and, before the introduction of modern endoscopic instruments, was performed under fluoroscopic control either in a freehand technique or by using a stereotactic frame. In Paris, the endoscopic ventriculostomy was established for pediatric patients by C. Sainte-Rose. In Gent, Belgium, in 1986 Caemaert et al. started endoscopic work in the ventricles including the treatment of suprasellar and colloid cysts.

In this period, neuroendoscopy was restricted to single pioneers scattered over the world. Their publications were like sparks without a long-lasting effect. The neurosurgical societies viewed these people as eccentrics who were not involved in the established microsurgical routine. This attitude toward endoscopy started to change when internationally recognized microneurosurgeons such as Perneckzky, Gaab, or Bauer started to take this technique seriously.

Development of Neuroendoscopy in the Ventricles Since 1990

The systematic basic research and development of neuroendoscopy are associated with 5 centers on the European continent; activity at these centers started nearly simultaneously and independently of each other. Notable participants in Germany were D. Hellwig and B. Bauer in Marburg; A. Perneckzky, P. Grunert, N. Hopf, K. Resch, and N. Hüwel in Mainz; and M. R. Gaab in Hannover, who continued at Greifswald and was later joined by J. Oertel and H. Schroeder. There were also A. Grotenhuis, a close friend of A. Perneckzky, in Nijmegen, the Netherlands, and J. Caemaert and L. Calliauw in Ghent, Belgium. These centers, although far apart geographically, had a common neuroendoscopic concept, common indications, and common endoscopic standards. They had synchronous development regarding neuroendoscopic technical innovations and an increase in clinical experience with a similar number of surgical patients. The exchange of opinions took place during endoscopic courses by inviting representatives of the other centers as guest speakers. Thus, despite some different opinions on details, the activity of these 5 centers can be summarized retrospectively due to their lasting effect abroad as a common “continental” development of modern contemporary neuroendoscopy. Note, however, that each center had its own history, presuppositions, motivations, and interests during the evolution of the technique.

In Hannover (at the Hannover Medical School), M. R. Gaab started his endoscopy development after being inspired by H. Griffith’s 1986 article. In 1987 he wrote a letter to all companies (in Europe, US, and Japan) that produced rigid and flexible endoscopes for clinical use at that time. There was basically one answer: “endoscopy in the brain would not be of clinical and commercial interest.” Only Karl Storz himself wrote a letter expressing great interest in the development of special endoscopic techniques for neuroendoscopy, and cooperation started on the first ETV and other ventricular pathologies in 1987. The first set (Fig. 2 right) for ventriculocystoscopy, ventriculostomy, and an approach to intraventricular lesions consisted of 4-mm Hopkins scopes with 0°, 30°, 70°, and 120° angles of vision and 18 cm in length for high-resolution diagnostic imaging. For surgical manipulation, a 2-mm Hopkins optics with a 0°, and later a 6°, angle of vision (toward the instrument) and an angulated ocular was used together with straight rigid instruments of 1.8 and 2.8 mm in diameter. In addition to mechanical instruments (forceps, scissors, needles, and so forth), monopolar and bipolar diathermy as well as a guide for laser fibers (Nd-YAG, holmium) allowed for quite effective surgery, including preventive hemostasis. A tube (sheath) of 6.5 mm in outer diameter was available—it could be guided stereotactically and used for puncturing the ventricle and cysts. Initially, the instruments were used with the aid of the surgeon’s eye behind a pair of sterilized eyeglasses (Fig. 1a). After successful application of the technique, a miniature endoscopy camera with high resolution (400 lines) and zoom optics was introduced, allowing a sterile operation with a sterile cover (Fig. 1b and c); the zoom optics presented an equal image size with different scope diameters. The relatively powerful instruments and hemostasis combined with an adjustable irrigation tube, which could be both positioned close to the bleeding and rapidly flushed to avoid contamination of the CSP, permitted, with increasing experience, not only biopsies of intraventricular lesions but also the complete removal of cysts (such as colloid cysts in the Monro foramen) and tumors from the ventricles and the ventricle wall. An ad-
vantage was the open sheath of this endoscope in contrast to scopes with small channels for instrument guiding and irrigation. The entire 6-mm inner diameter of the tube could be used for removal of material—from cysts to larger tumor pieces. Initially, only the 0° and 30° optics could be sterilized.14,15,45 After Gaab’s appointment to the chair at the University at Greifwald in 1992, the development of neuroendoscopy could be accelerated. For several years, Codman distributed the instruments in the US. The cooperation with H. Schroeder and J. Oertel allowed further progress with statistical evaluations, and the synergy was continued when Gaab followed M. Samii as the chairman of the Hannover Nordstadt Hospital in 2002 and was again joined by J. Oertel. Today, all the Hopkins optics of the GAAB 1 system are of the improved Hopkins II type and can be sterilized by autoclaving (Fig. 2 left). The combination with neuronavigation since 1986 has made the approach more precise; this allows the endoscopic treatment of multicystic hydrocephalus as well as the use of cystostomies in arachnoid and other cysts.37

In Marburg, Hellwig and Bauer started with neuroendoscopy in 1988. Before applying this technique in patients, the topographical anatomy of the ventricular system was extensively examined.41 In 1990 preliminary results on endoscopic stereotaxy with an ultrathin flexible endoscope (diameter 1.4 mm), which could be used in combination with the Riechert-Mundinger stereotactic frame, were published (Fig. 3).21,23 At that time, the main indication for stereotactic endoscopic interventions was biopsies of intracranial space-occupying lesions under visual control, but other indications were recognized over the course of time. Endoscopic stereotactic procedures have been performed for the treatment of hydrocephalus, hematoma evacuation, cyst aspiration (especially of the cranial midline), and abscess drainage.22,24 Similar to Wickham and Fitzpatrick’s49 use of the term “minimally invasive surgery,” Hellwig and Bauer defined these procedures as minimally invasive neurosurgery (MIN), that is, interventions in which the use of endoscopes avoids larger openings of the intracranial or intraspinal spaces.21

The flexibility and steerability of their endoscopes also made it possible to perform interventions in the subdural space and the spinal canal, a definite advantage. The indication spectrum has been enlarged by the improvement and further development of miniaturized auxiliary instruments, such as microscissors, microdissectors, balloon catheters, microrinsing and suction systems, flexible probes for mono- or bipolar electrocoagulation, and ultrathin bare laser fibers.24 Since 1996, the group changed to rigid endoscopes combined with neuronavigation for several reasons. The optical quality and specifications of rigid neuroendoscopes improved markedly. Therefore,
flexible, steerable endoscopes were reserved for interventions in the posterior part of the third ventricle or in the spinal canal. On the other hand, frame-based techniques had several limitations. The stereotactic frames are bulky and sometimes interfere with endoscopic procedures. Most important, frame-based stereotactic systems do not provide the surgeon with ongoing feedback about anatomical structures in the surgical field. The endoscopic view of intraventricular anatomy is different from that in microsurgery, which is familiar to neurosurgeons. Three-dimensional image software in combination with modern computer technology is helpful for preoperative virtual planning and simulating endoscopic approaches (Fig. 4).

In 2000, the results of the relationship between virtual-reality neuroendoscopic simulations and actual imaging were published.40 Furthermore, the virtual system is a valuable tool for training—not only for neuroendoscopically inexperienced surgeons but also medical students.

In Mainz, Axel Perneczky was appointed professor at the Johannes Gutenberg University in October 1988, and he started on basic endoscopic work in 1989. He was assisted by Klaus Resch, a neurosurgeon with experience in anatomy and postmortem inspections, which he performed in scientifically interesting neurosurgical patients with the permission of their relatives. For this latter purpose, he used an endoscope to minimize the trauma of the approach and to keep the patient in a cosmetically unchanged state. Through these inspections, Resch and Perneczky recognized the superiority of the rigid Hopkins endoscope over flexible fiberscopes for application in the ventricles. The arguments for using a rigid endoscope in the ventricle were a much better optical quality and easier handling of the endoscopes. Finally, at least for performing an ETV, a straight trajectory through the foramen interventriculare of Monro was sufficient. Given the increasing frequency of these procedures, a topographical endoscopic anatomy had to be established. Manfred Tschabitscher, a professor of anatomy in Vienna, Austria, used different keyhole approaches in dye-prepared cadavers to study the anatomy inside the ventricles from an endoscopic view. Among other anatomic landmarks, the importance of the choroid plexus, as a leading structure to the foramen interventriculare, and the tuber cinereum between the recessus infundibularis and the corpora mammillaria in front of the basal artery as the safest place for perforation were intensively studied from the endoscopic transventricular view. For safer handling and stable fixation of the endoscope, the first ETV operations in Mainz were done with stereotactic guidance using the 6-mm Wolf cystoscope and CRW stereotactic frame (Fig. 5A and B). Grunert adapted and improved the stereotactic technique of Kelly so that the whole procedure, including the perforation of the ventricular floor, was performed under visual control. In axial CT slices, the coordinates of 2 target points were calculated: one at the level of the foramen of Monro and a second at the level of the dorsum sellae in the midline in front of the basal artery. These 2 points defined the optimal trajectory, and either no or only
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minimal intraoperative correction of the endoscope position was required. The first ETV procedure by this team was performed in 1992 (Fig. 5C). Because of its great safety and clinical success, this stereotactic technique was maintained for the next 40 procedures. Stereotactically relevant problems with the instrument’s introduction through the foramen interventriculare from different angles by using endoscopes of different diameters in the first patients were described in 1994.27 With this frame-based technique, suprasellar and paraventricular cysts close to the wall of the third ventricle were shunted into the ventricle, often via a contralateral approach, which allowed superior control of the whole lesion.28 As experience and surgical confidence increased and as more suitable endoscopes with a shorter shaft and lighter camera systems became available, the freehand technique was introduced in Mainz in 1994. Initially, endoscope fixation systems became available, the freehand technique was able endoscopes with a shorter shaft and lighter camera systems allowed A. Perneczky to use endoscopes in the subarachnoid space and to use their excellent light quality in the depth during microsurgical procedures. This combined operative technique was termed “endoscope-assisted microsurgery” and constituted a central part of his general neurosurgical concept of keyhole surgery.38 The introduction of frameless stereotaxy replaced the time-consuming frame-based stereotaxy for endoscopic purposes.27,28 Nevertheless, frameless stereotaxy remains the gold standard for endoscopic approaches whenever a very accurate trajectory is required.

Conclusions

Neuroendoscopy has tremendously evolved since its beginnings in the early 20th century. Especially for this subdiscipline of neurosurgery, the technical development of good-quality endoscopes providing a good view and accurate information on the surgical target as well as adjacent delicate structures has been of major importance. In addition to this technical development, the personal impetus of each involved neurosurgeon had a significant influence on the introduction of the neuroendoscopic technique in Europe. In Europe, and particularly in Germany, there were 3 major centers from Mainz, Hannover/Grefwald/Hannover, and Marburg. Numerous publications have appeared and cannot be reviewed in more detail. Besides the technical developments and these publications, all groups have organized important internationally recognized congresses and courses over the years. Important study groups such the German Society for Neuroendoscopy or the International Study Group on Neuroendoscopy have been founded by individuals from this group of neurosurgeons. However, despite the tremendous individual developments and very different theoretical principles at the beginning, the most important issue is that all research groups arrived at similar solutions in the end: the application of freehand, rigid rod-lens scopes in the daily routine with the opportunity to apply frameless or frame-based neuronavigation as well as steerable scopes in more complex cases.

Disclosure

Dr. Gaab is a consultant for the Karl Storz Company.

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