In his article entitled "Limited Exposure in Cerebral Surgery", published in 1971, Donald H. Wilson quoted the famous neurosurgeon William Halsted, who, in 1924, expressed his belief "*that the tendency will always be in the direction of exercising greater care and refinement in operating*" [Wilson 1971]. Today, on the threshold of the third millennium, this fundamental philosophy of minimally invasive therapy should be emphasized more than even before, operating with a minimum of iatrogenic trauma and achieving a maximum of efficiency.

In this first volume of our publication, we intend to demonstrate different keyhole approaches for the surgical treatment of intracranial and skull base lesions. Each chapter describes the historical development of the craniotomy, the anatomical construction of the target region and, most importantly, the surgical approach. Concentrating on surgical practice, patient positioning and orientation based on superficial anatomical landmarks, the stages of the craniotomy, intradural dissection, and wound closure are described in detail. Dealing with different approaches, a consequent way, patient's positioning and the extradural stages of the craniotomy are illustrated with artistic drawings and the intradural dissection with fresh human cadavers. Potential errors, their consequences and important tips and tricks are also given, providing instructions for everyday use.

In the second volume of the book, scheduled to appear in 2008, we will present demonstrative operative cases treated via keyhole approaches. Patient history, medical reports and neurological appearance will be described; special attention will be given to preoperative neuroradiological diagnostics, e.g., computed tomography (CT), magnetic resonance (MR) tomography including MR angiography and functional imaging, and, if performed, digital subtraction angiography (DSA). Three-dimensional preoperative approach planning will be discussed, in particular using stereoscopic evaluation of the radiological data in virtual reality. Of course, minimally invasive keyhole surgery with well documented intra- and postoperative course of each patient will be presented in detail.

1.0 Introduction

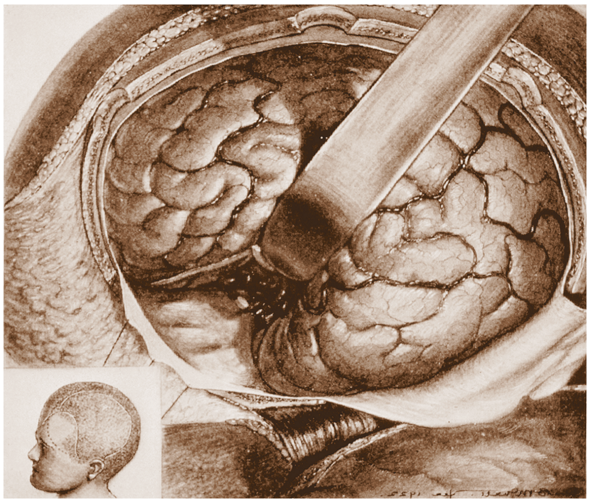


Fig. 1.0.1 *Dandy's frontotemporal craniotomy exposing sellar and parasellar lesions. Note the extensive exploration causing unavoidable injury to the cortical surface. In the 1920s and 1930s, craniotomies of this size were necessary to bring enough light into deep-seated areas for manipulation with macrosurgical instruments. Note that approaching a pituitary tumor, Dandy severed the left CN II to obtain optical monitoring of tumor removal.*

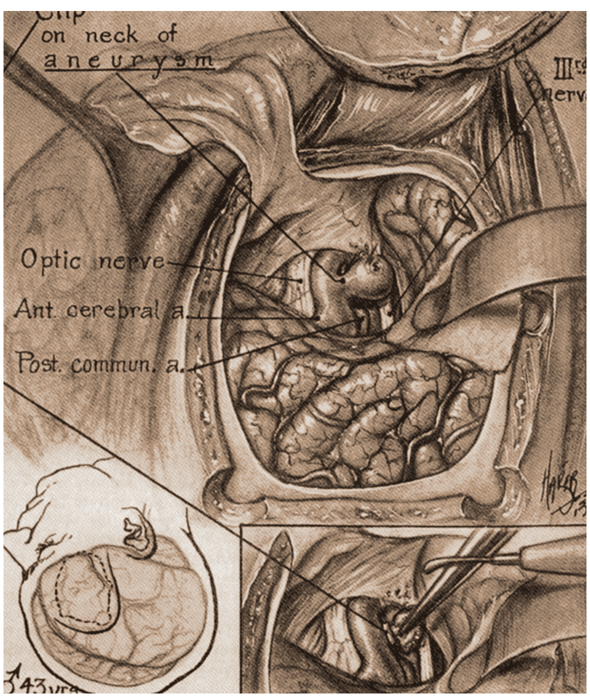


Fig. 1.0.2 *In 1938, Dandy described the so-called hypophyseal approach, exposing the suprasellar area. Note the significant limitation of skin incision and cranial opening, documenting Dandy's learning process in reducing surgical trauma. The illustration shows the first clipping of an intracranial aneurysm, causing oculomotor palsy due to local compression of the CN III.*

Evolution of neurosurgical techniques: from macrosurgery to the minimally invasive keyhole surgery

Approximately one hundred years ago, neurosurgical therapy of intracranial lesions was performed with extended craniotomies (Fig. 1.0.1). At that time, such large approaches were necessary for several reasons. First, on account of sparse and simple diagnostic techniques, the size and site of pathological lesions could not be accurately determined; therefore, the craniotomy had to be large enough to find the lesion within the intracranial space. Second, because of the undeveloped attitude toward health problems, intracranial lesions were only diagnosed when they had reached immense sizes; therefore, the craniotomy had to be large enough to remove these large, space-occupying tumors. Third, illumination in operating theaters was poor; therefore, the cranial opening had to be large enough to bring light into the surgical field. Fourth, instruments at that time were not designed for neurosurgery but for general surgery and they were too large to be used within narrow openings. In addition, neurosurgical teams consisted of at least three members, thus, six hands and their large instruments obscured the surgical field and the craniotomy had to be large enough to allow sufficient observation of the site.

With the evolution of preoperative diagnostic tools, intraoperative illumination devices and neurosurgical instruments, the discovery of fundamental anatomical and physiological principles have allowed a tremendous development in neurosurgical techniques making such interventions less dangerous and less traumatizing (Fig. 1.0.2).

The first important factor in the development of neurosurgical techniques was the evolution of preoperative diagnostic imaging. In 1918, radiographic techniques were introduced into neurosurgery by Walter E. Dandy [Dandy 1913]. With the help of air injection and fluoroscopy of the ventricle system during the so-called ventriculography, he was able to demonstrate the deformed and dilated ventricles and verify the diagnosis (Fig. 1.0.3). A further milestone was achieved when Edgar Moniz described the technique of cerebral angiography which he called "arterial encephalography" (Fig. 1.0.4). In 1927, after experiments on animal models and cadavers, he was able to show intracranial vessels of a 20-year-old patient [Moniz 1927].

In 1932, Norman M. Dott demonstrated the first picture of an intracranial aneurysm and Herbert Olivecrona published his experience on the angiographic appearance of parasagittal meningeomas [Dott 1932, Olivecrona 1943]. The method of direct arterial puncture was improved by Sven-Ivar Seldinger with a catheter replacement technique which was later refined by René Djindjian resulting in the technique of superselective angiography [Seldinger 1953, Djindjian 1975]. However, Dandy's ventriculography and Moniz' angiography allowed only an indirect observation of the brain with its ventricular chambers and vessels. The first direct visualization of brain tissue increased the further development of diagnostic facilities using "computerized axial tomography" (CT), described by Allen M. Cormack, Godfrey N. Hounsfield and James Ambrose in the early 1970s (Fig. 1.0.5). After much development, magnetic resonance imaging (MRI) enabled not only the precise diagnosis but also the accurate determination of topographic relations of specific lesions to individual anatomical structures [Hounsfield & Ambrose 1973, Lauterbur 1973, Damadian 1977, Goldsmith 1977].

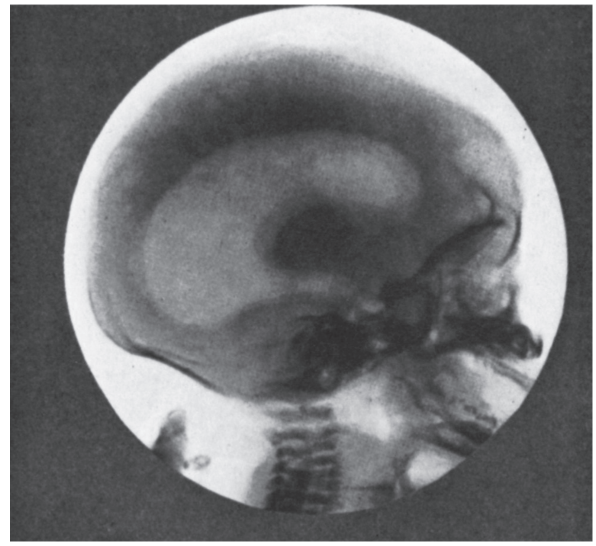


Fig. 1.0.3 *Ventriculogram of a child suffering from severe hydrocephalus. This photograph was published by Dandy in 1913 in his ground-breaking paper "Ventriculography following the injection of air into the cerebral ventricles".*

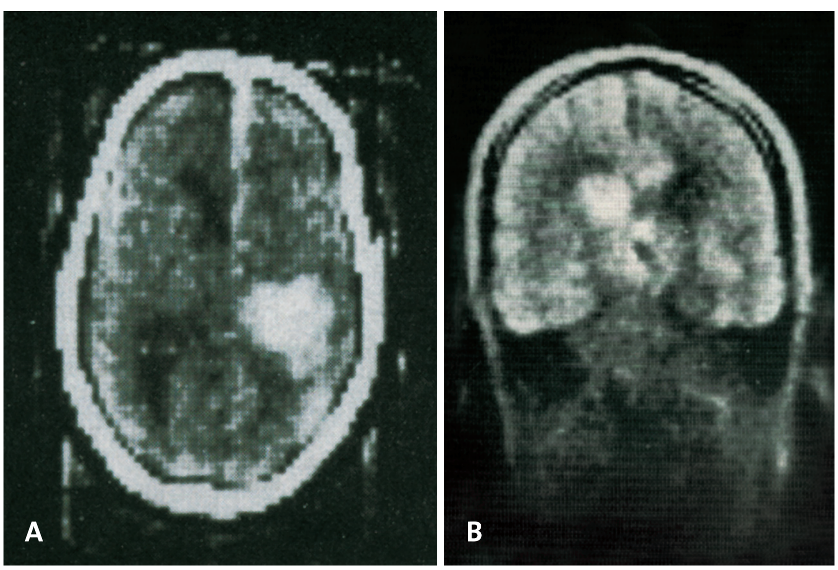


Fig. 1.0.5 *One of the first CT scans published by Hounsfield in his fundamental article "Computerized transverse axial scanning tomography" in 1973 (A). Note the displacement of the ventricles according to a space-occupying bleeding of the left basal ganglia. An early coronar MRI scan of a craniopharyngeoma from the Nottingham facility in 1980 (B).*

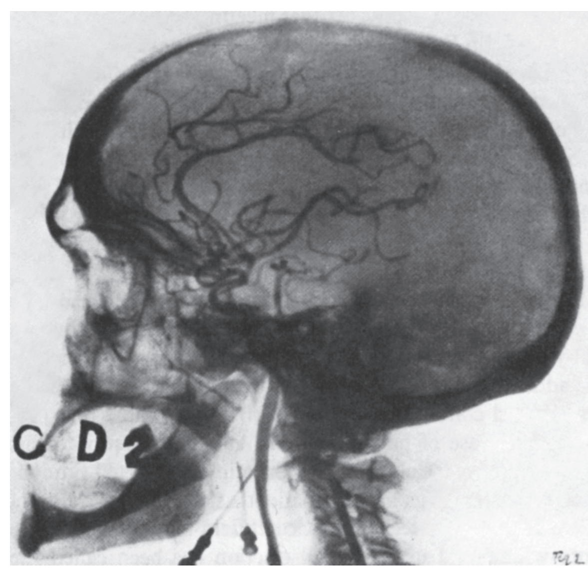


Fig. 1.0.4 *In 1927, Moniz published in his article "Arterial encephalography, its importance in the localization of cerebral tumors" the arterial network of the internal carotid artery in 20-year-old men. He injected a 30% solution of sodium iodide directly into the carotid, which was well tolerated by the patients.*

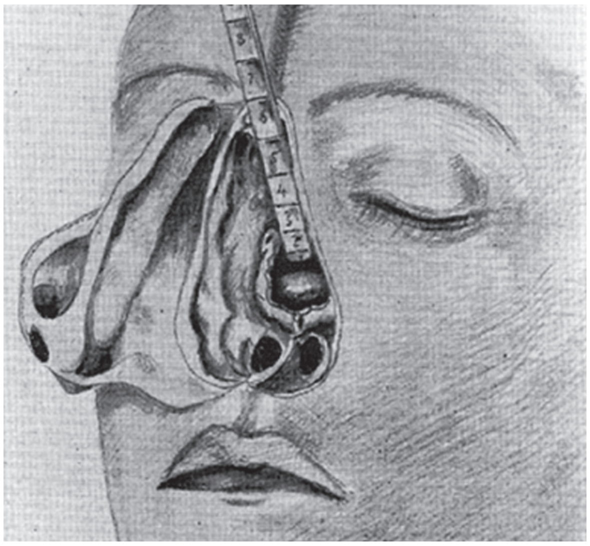


Fig. 1.0.6 *SCHLOFFER carried out the first transsphenoidal pituitary operation on 16 March 1897. The patient was a 30-year-old man who suffered from hypopituitarism, visual disturbance and progressive signs of elevated intracranial pressure. Despite an invasive approach with removal of the septum, nasal turbinates, ethmoid cells, and the medial wall of the left orbit, the intraoperative orientation was complicated. Schloffer therefore measured the distance from the glabella to the anterior aspect of the sella on a preoperative radiograph and used the measurement to "sound out" the surgical cavity with a "dipstick".*

The second important factor in the evolution of neurosurgical techniques was the development of intraoperative illumination devices. Today it is almost impossible to imagine that HERMANN SCHLOFFER, director of the neurosurgical department in Innsbruck, Austria, performed his first transsphenoidal surgery in 1907 without any illumination or magnification tools (Fig. 1.0.6). Some years later, HARVEY CUSHING used a head-mounted lamp for his transsphenoidal macrosurgical approach (Fig. 1.0.7). At about this time, PAUL C. BUCY wrote in his publication "Neurosurgery in darkness", describing a surgical procedure of OTFRID FOERSTER: *"The scene was a primitive one. The only source of illumination of the operating field was a student lamp with a brass reflector. It was held in my hand, which soon became unsteady much to Foerster's disgust"* (Fig. 1.0.8) [SCHLOFFER 1907, CUSHING 1914, BUCY 1930].

Fig. 1.0.7 *CUSHING's sublabial transseptal approach for pituitary tumors. Note the head-mounted lamp allowing sufficient illumination of the deep-seated surgical field.*

Fig. 1.0.8 *FOERSTER's operating theater for transcranial surgery in the autumn of 1930. PAUL C. BUCY is on the left side of the photograph in street clothes holding a student lamp.*

Of course, the real revolution in illumination of the surgical field was the use of operating microscopes which enabled inauguration of the microsurgical area in the 1960s and early 1970s.

While other surgical fields such as gynecology, urology, and, especially otology adopted the microscope for daily routine procedures very quickly, most neurosurgeons were reluctant to use it. However, Dwight Parkinson, one of the real pioneers of microneurosurgery pointed very clearly the advantages of this new device: *"Early in 1960 the neurosurgical section borrowed an operative microscope from the otolaryngology department. The microscope provided us with the enormous advantages of coaxial illumination, magnification, and simultaneous viewing for the surgeon and resident"* [Parkinson 1995]. The first neurosurgeon who used a surgical microscope was Theodore Kurze for treating an acoustic neurinoma on 1 August 1957. Kurze published his experiences in several publications amongst others in an article entitled "Microtechniques in neurological surgery" [Kurze 1957, 1964]. In 1968, Robert W. Rand and Peter J. Jannetta made an important contribution to the evolving field of neurosurgery with the article "Microneurosurgery: application of the binocular surgical microscope in brain tumors, intracranial aneurysms, spinal cord disease, and nerve reconstruction" [Rand & Jannetta 1968]. After experimental studies, M. Gazi Yasargil demonstrated the utility of the operating microscope for the treatment of brain tumors and vascular malformations (Fig. 1.0.9). Jannetta reported the advantage of the surgical microscope for microvascular decompression of cranial nerves [Yasargil 1966, 1969, 1970, Jannetta 1970].

The introduction of microscopic visualization of the surgical field was followed by the invention of adequate surgical instruments (Figs. 1.0.10, 1.0.11). The technique of bipolar coagulation was successfully adopted for microneurosurgery by James Greenwood and Leonard Malis, and fine microinstruments were developed for intracranial and spinal use [Kurze 1963, Malis 1967, 1979, Yasargil 1969].

Despite the above mentioned development of preoperative diagnostics, illumination devices and microneurosurgical techniques, intracranial neurosurgery was characterized in the 1970s and 1980s, and also in the 1990s by large, extended craniotomies.

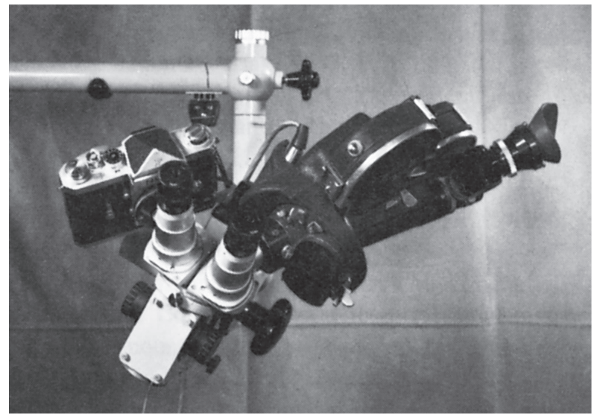


Fig. 1.0.9 *An early OPMI I Zeiss operating microscope with camera units in place used by Yasargil in the 1970s.*

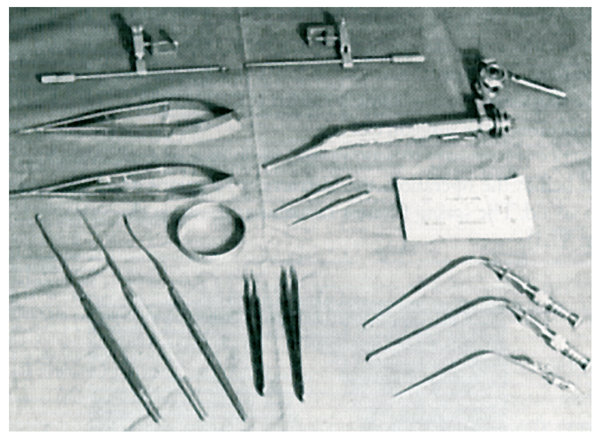


Fig. 1.0.10 *Kurze's microsurgical equipment published in his pioneering article "Microtechniques in neurological surgery" in 1964.*

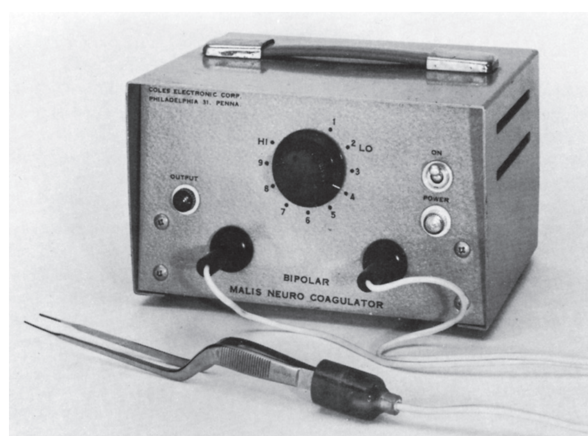
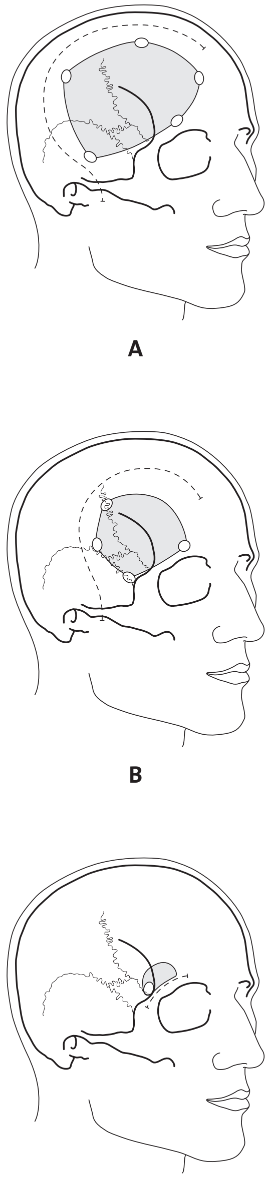


Fig. 1.0.11 *A Malis bipolar coagulator for neurosurgical use. Note the attached forceps allowing careful surgical dissection.*



A

B

C

Fig. 1.0.12 *Schematic drawing demonstrating the stepwise development of the frontotemporal subfrontal approach. Note the reduction in size of the skin incision and craniotomy compared to* Dandy*'s macrosurgical frontotemporal approach (A) and to* Yasargil*'s pterional craniotomy using microsurgical techniques (B). The supraorbital keyhole craniotomy, representing the frontobasal part of* Yasargil*'s pterional approach, allows a markedly reduced extension of the craniotomy with subsequently less surgical damage to the extra- and intracranial structures (C).*

However, since the very onset of neurosurgery there has been a widely accepted fact that exposure of brain tissue for several hours during surgery using these extended approaches always means injury to the brain surface by nonphysiological surroundings such as room air, irrigation, cover material, or spatula pressure. Note that these cortical microinjuries were possibly the reason for the previous necessity of routine postoperative anticonvulsive medication in all patients undergoing intracranial surgery. In order to gain an impression of dimensions of cortical exploration and surgical trauma, the area of brain surface exposed for a limited craniotomy of approximately 2 cm should be compared with the area exposed during a conventional craniotomy with a bone flap diameter of approximately 8 cm. Using the equation $r^2 \times \pi$ for the calculation of the area of a circle in which r is the radius of a circular bone flap, the following results could be obtained: area of brain surface exposed during conventional craniotomy with 8 cm diameter: $r^2 \times \pi = 4\ cm^2 \times \pi = 50.27\ cm^2$; area of surface approached during limited craniotomy with 2 cm diameter: $r^2 \times \pi = 1\ cm^2 \times \pi = 3.14\ cm^2$. We can see that in choosing a limited approach to specific lesions, it becomes possible to dramatically reduce injury to the cortical surface.

At the same time, limited craniotomy reduces the necessity of rough brain retraction. Since Eugene M. Landis in 1934 described the physiological range of capillary pressure, it has been shown in a number of experimental and clinical studies and has become a widely accepted fact that brain retraction exceeding certain limits causes significant intraoperative trauma to brain tissue and may cause permanent neurological deficits [Landis 1934, Albin 1975, 1977, Miller 1973, Yokoh 1983, 1987, Rosenorn 1985, Hongo 1987, Andrews 1993, Fries 1996, Yundt 1997]. In order to minimize brain retraction, various methods have been proposed, e.g., application of special anesthetic techniques to achieve brain relaxation, special brain retractor systems, and special patient positioning techniques. However, the best retraction is no retraction. Careful choice of an adequate, less invasive surgical approach with minimal brain exploration and retraction results in a significant reduction of damage to intracranial structures (Fig. 1.0.12).

In 1971, Donald H. Wilson mentioned that *"we make no fetish of keyhole surgery. A large arteriovenous malformation, hemispherectomy, and some epilepsy surgery would certainly require large standard craniotomies"*. He was one of the first neurosurgeons to use the term keyhole surgery describing the extension of limited trephinations [Wilson 1971].

However, it is important to note that with the expression “keyhole” not only the extension of the craniotomy should be described. The term keyhole should explain moreover a concept approaching pathological lesions in definite intracranial areas. The aim of keyhole neurosurgery is not the limited craniotomy, but the limited brain exploration and minimal brain retraction. In this way, the limited craniotomy is not the goal but the result of the philosophy of minimal invasiveness in neurosurgery. The craniotomy should be as limited as possible to offer minimal brain trauma, although as large as necessary to achieve a safe surgical dissection.

Here it is essential to notice that all large sized approaches in neurosurgery can be imagined as a side-by-side combination of several small approaches (Fig. 1.0.13). Therefore, in the planning and performance stages of any microsurgical approach, the surgeon’s own critical reflection on the necessary and unavoidable manipulations and exposures during a given surgical access will be one of the most important steps in the development of his personal comprehension of the keyhole concept in microneurosurgery. The goal of keyhole surgery is to choose and perform the most ideal approach according to this critical reflection depending on the individual pathoanatomy of the patient as well as on individual personal experience, attitude, and capability.

In choosing the correct keyhole approach to a specific lesion, it becomes possible to dramatically reduce the size of the craniotomy with less need for dura opening and less brain exposure and retraction. These advantages of minimally invasive keyhole microsurgery may contribute to improved postoperative results including shorter hospitalization time because of reduction in the risk of complications such as bleeding or re-bleeding with neurological deterioration, leakage of CSF, infection, scarification, and cosmetic disturbances.

However, the use of limited approaches causes different shortcomings during the procedure such as the predefined surgical corridor, decreased intraoperative orientation, narrow viewing angles with an almost coaxial control of the microinstruments, and reduction of light intensity in the deep-seated operating field.

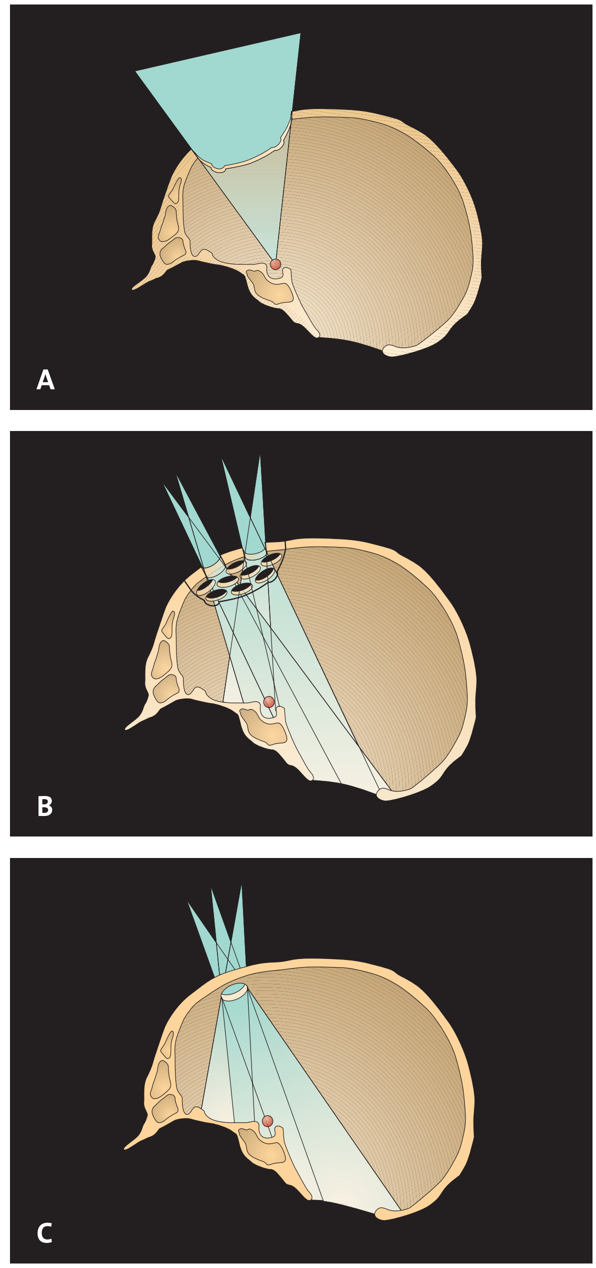


Fig. 1.0.13 *Schematic drawing of a large sized standard approach with funnel-like narrowing of the surgical field exposing deep-seated lesions (A). Extended craniotomies can be considered as a combination of several limited keyhole approaches (B). Entering the intracranial chamber through a correctly performed limited opening, the visual field shows a sector-like widening (C). A short distance allows a limited overview; in contrast, a long surgical corridor to a deep-seated surgical field often provides a better monitoring of the surgical dissection. In many cases, this consideration may result in the employment of contralateral approaches.*

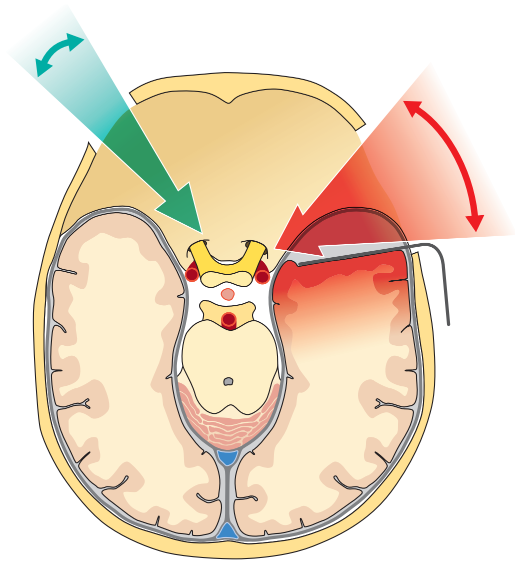


Fig. 1.0.14

predefined surgical corridor

individual tailored approach

Problem I Because of the predefined surgical pathway, the corridor of dissection cannot be changed during surgery; therefore, the craniotomy should be tailored exactly according to the pathoanatomical situation of the individual patient. In this way, the keyhole concept is based on a careful preoperative study of diagnostic images. Using modern tools, the exact anatomy and pathology of the patient can be precisely described. Anatomical pathways and corridors can be determined, providing optimal access to the pathological processes. According to the individual pathoanatomical situation and to the individual experience of the surgeon, a tailored, individual approach can be carried out. This individual least damaging and therefore minimally invasive approach to the target region helps to avoid retraction of sensitive structures and unnecessary exploration of the cortical surface.

The consequence of the concept of the individual surgical therapy is that after meticulous overview of the preoperative diagnostics and planning of the procedure, the surgeon should perform the surgical approach himself. Self-made surgery includes self-made positioning of the patient, self-made skin incision, self-made craniotomy and self-made surgical exposure of the target region. The individual, minimally invasive and maximally effective surgical approach to the intracranial lesion is the central question of keyhole neurosurgery; therefore exploring the pathology is the task of the operating neurosurgeon himself and not an assistant! This principle of the tailored minimally invasive keyhole neurosurgery is in direct contrast to a standard surgical therapy via extended standard surgical approaches.

In this way, preoperative planning and self-made performing of the tailored surgical approach is the most important part of keyhole neurosurgery (Fig. 1.0.14).

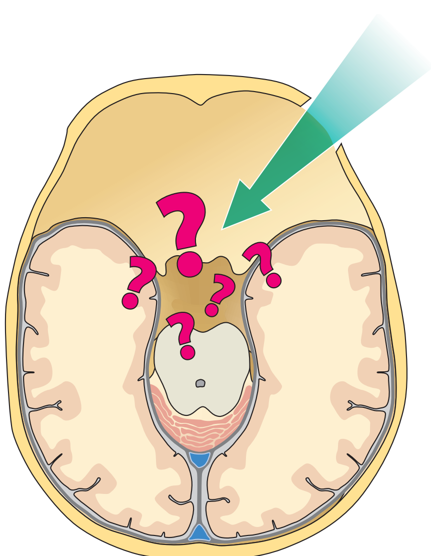


Fig. 1.0.15

limited orientation

self-made exploration
intraoperative imaging
neuronavigation

Problem II The second drawback of keyhole procedures is the decreased intraoperative orientation. In our experience, the individual preoperative planning according to the individual pathoanatomical situation and the individually performed exposure according to the surgeons experience offer safe dissection despite limited approaches. In addition, the use of navigation devices, ultrasound units, intraoperative CT and MRI may be helpful if the limited cranial opening has caused a confused and poorly overviewed situation (Fig. 1.0.15). Nevertheless, these technical tools can never replace the precise and particular anatomical knowledge of the target region!

Problem III The narrow viewing angle and almost coaxial control of dissection causes an additional problem. According to our experience, if the craniotomy is smaller than 15 mm, the intraoperative use of conventional microinstruments becomes very limited. For this reason, the development and intraoperative use of new tube-shaft microinstruments, e.g., scissors, grasping and coagulating forceps, clip applicators, is mandatory for performing keyhole surgery (Fig. 1.0.16).

Problem IV The eyes of the neurosurgeon must be able to see anatomical structures to save them and to recognize pathologies to attack them. The fourth main difficulty of keyhole approaches is the loss of intraoperative light and sight through the limited craniotomy, causing significantly reduced optical control during surgery. For the purpose of bringing light into the surgical field and controlling deep-seated microinstruments with an adequate magnification, surgical microscopes can be effectively supplemented by the optical properties of modern endoscopes (Fig. 1.0.17). The three advantages of endoscopes are as follows: 1) increased light intensity, 2) extended viewing angle, and 3) clear depiction of details in close-up positions. The first surgeons who realized the limitations of surgical microscopes were Werner Prott in 1974 when he performed diagnostic endoscopic cisternoscopy of the cerebellopontine angle, Michael L. J. Apuzzo in 1977 when he introduced the so-called side-viewing telescope, and Falk Oppel in 1981 when he applied intraoperative endoscopy during procedures of microvascular trigeminal decompression [Prott 1974, Apuzzo 1977, Oppel 1981]. All of these descriptions can be regarded as the initiation of endoscope-assisted microneurosurgery, which, along with other neuroendoscopic techniques, experienced a revival in the 1990s.

Modern three-chip microcameras with separate transmission of the red, green, and blue video signals provide excellent image quality. The endoscopic video signal is recorded and displayed on a video monitor which should be ideally placed in front of the surgeon. Recently, the evolution of camera technology has enabled replacement of the operating microscope. The so-called exoscope enables neurosurgeons to perform complicated cranial surgeries without using the microscope: the exoscope offers visualization of the surgical field “from outside”, the endoscope “from inside” (Figs. 1.0.19, 1.0.20). A futuristic opportunity is currently being developed with head-mounted LCD screens which allow the surgeon to take his eyes off the microscope oculars (Figs. 1.0.18, 1.0.19). Moreover, this

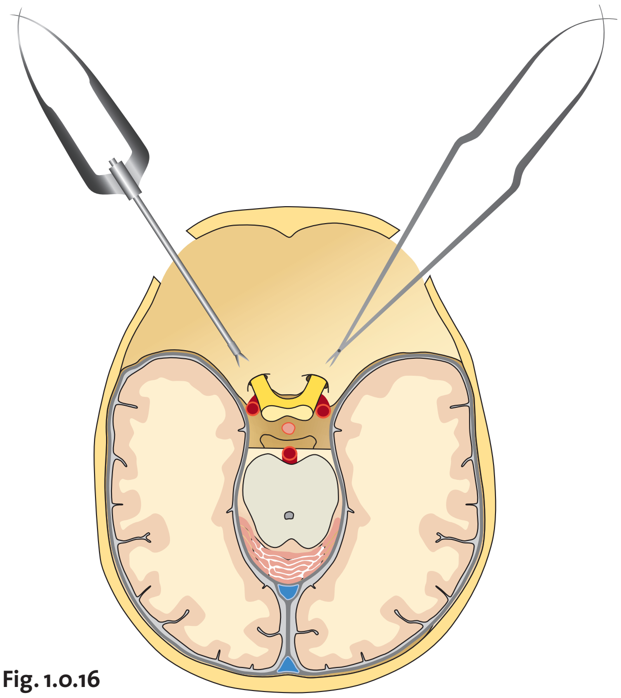


Fig. 1.0.16

narrow surgical corridor

special instrumentation

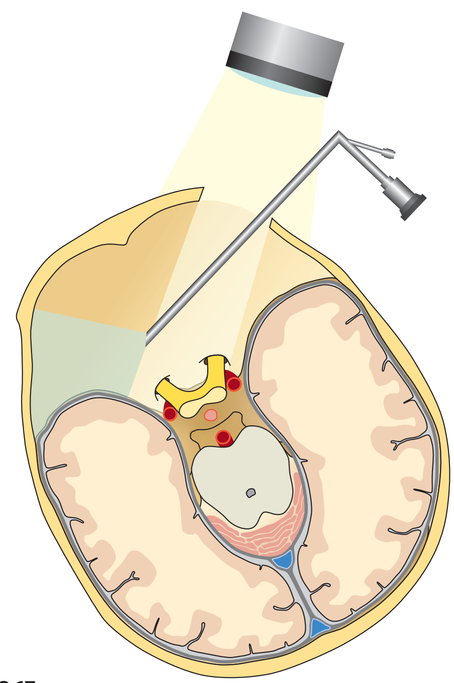


Fig. 1.0.17

limited visual control

endoscope-assisted microneurosurgery

display system allows importing of different digital images such as diagnostic pictures and information of navigation devices, directly into the head-mounted LCD screens. The use of the picture-in-picture mode may result in an efficient visualization during the surgical procedure.

Fig. 1.0.18 *Photograph from the operating theatre showing the intraoperative use of an endoscope, designed for intraventricular procedures (Aesculap AG, Tuttlingen, Germany). Note the intraoperative application of a head-mounted LCD screen, manufactured by Vista Medical Technologies, Carlsbad, California, USA. The photograph clearly shows that the surgeon has a comfortable and ergonomic working position during the whole procedure.*

Fig. 1.0.19 *Photograph illustrating the intraoperative use of an exoscope (Olympus Company, Tokyo, Japan) and a head-mounted LCD screen during a keyhole procedure. The superior image quality of the exoscope enables to perform minimally invasive keyhole surgery without intraoperative use of a surgical microscope.*

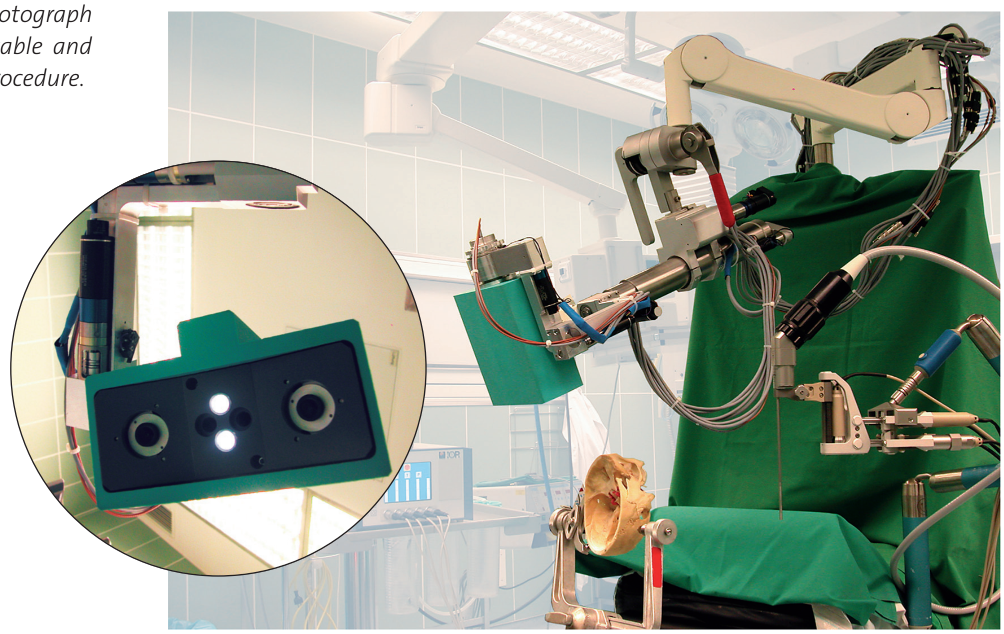


Fig. 1.0.20 *Prototype demonstrating a binocular exoscope which will be developed in the "MINOP II Study" in cooperation with Aesculap AG, Tuttlingen, Germany.*

General techniques for keyhole neurosurgery

Personnel, operating theater ergonomics, and instrumentation

Operating theater personnel

Operating theater personnel play a vital role when performing keyhole procedures. The proper education and training of surgical assistants, nurses and technical assistants are mandatory for safe intraoperative care.

The assistant should have training in neurosurgical anatomy and be familiar with general microsurgical techniques. Due to the limitation of approaches, an assistant's direct participation in performing surgical maneuvres becomes very restricted. However, in several situations the assistant can help in various ways, including suctioning, coagulating, cutting and gently retracting. The new generation of microscopes gives the assistant binocular vision which allows the associate to work and assist at ease. In our department, the assistant is in charge of bipolar coagulation according to the surgeon's advice. A device with voice control will be developed in the future.

The scrub nurse should understand the basic goal of the surgical event and be able to follow the procedure on the monitor. The nurse should be familiar with the neurosurgical equipment and deliver instruments to the surgeon's hands ready for use without requiring the surgeon to look away from the surgical field and the microscope.

The circulating nurse obtains necessary instruments and solutions and works closely with the scrub nurse. In addition, the circulating nurse should be able to set up microsurgical equipment, e.g., microscopes, endoscopes, navigation devices, bipolar units, C-arm fluoroscope tools. As a technical assistant, the circulating nurse should be trained and able to deal with any malfunctioning equipment.

Operating theater layout

Today's neurosurgical operating theaters must be large enough to accommodate the patient, the operating personnel and highly sophisticated neurosurgical equipment.

The basic organization of the operating theater in our department is shown in Fig. 1.0.20. The patient is brought on the operating table in

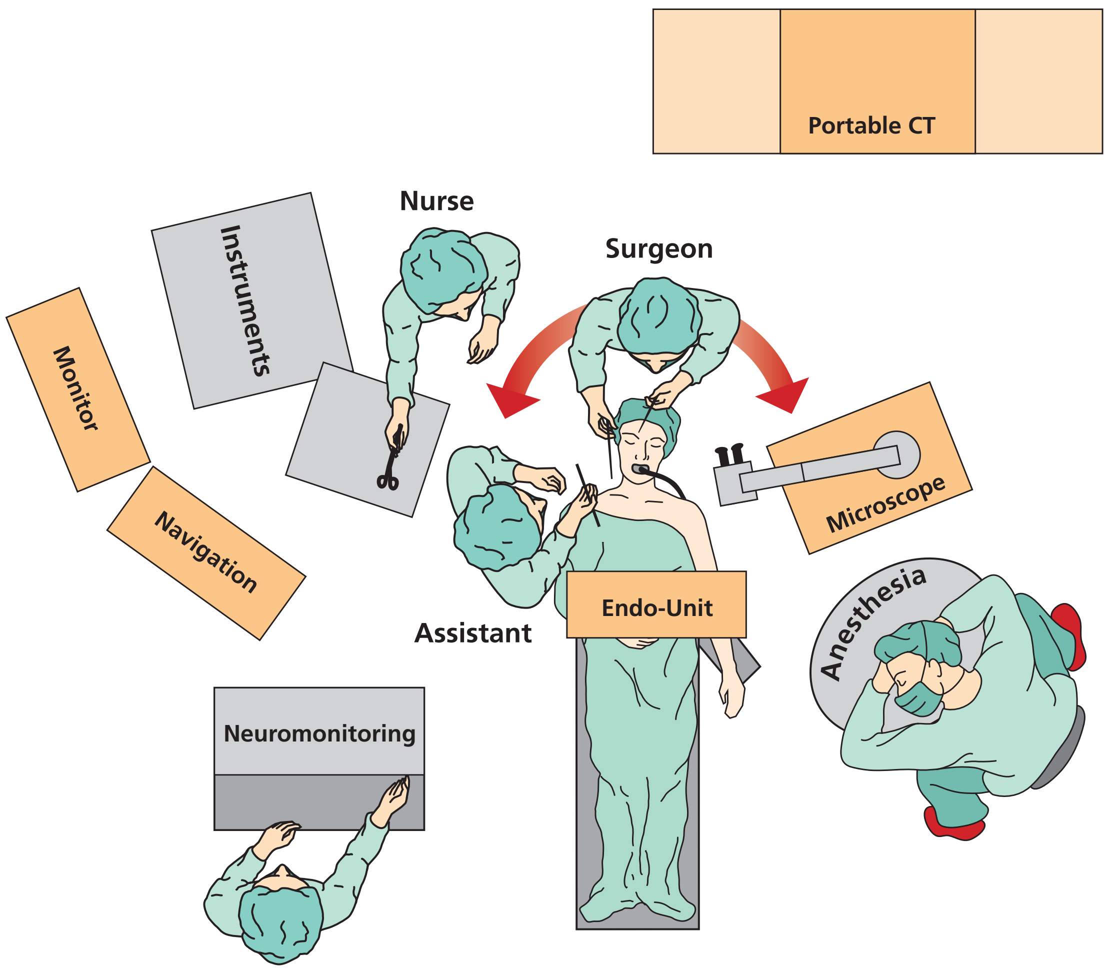


Fig. 1.0.21 *Schematic picture showing operating theater layout when performing keyhole surgery.*

the supine or prone position according to the surgical target region. The surgeon stands directly at the head with his assistant on the right side. The scrub nurse sits or stands between the surgeon and the assistant, allowing precise assistance. The anesthesiologist with his equipment is on the left side of the patient. This organization allows frequent changes in the surgeon's position when performing keyhole exposures.

The microscope is on the left side of the surgeon and the video monitor is in such a position that the nurse and the anesthesiologist can both follow the procedure. If used, the monitor for endoscopic visualization is placed directly in front of the surgeon. Frequently, additional equipment is also used during keyhole surgery. Intraoperative CT or MR scan, navigation devices and ultrasound units are used in several tumor cases and a C-arm fluoroscope in neurovascular surgery. However, the relation between the neurosurgeon's position and that of the patient is a sensitive one that is often impaired during surgery. The large number of highly sophisticated tools should not hamper efficiency in the operating theater.

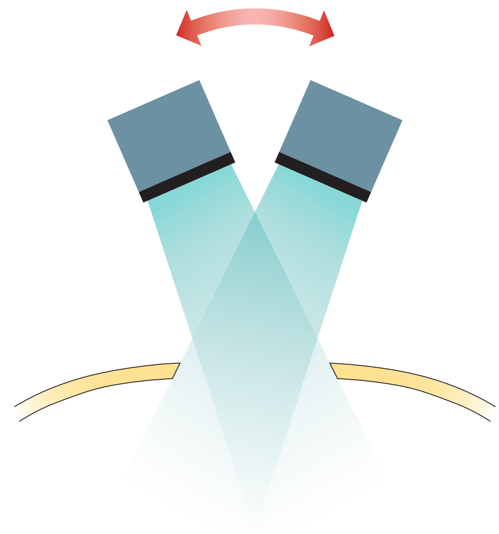
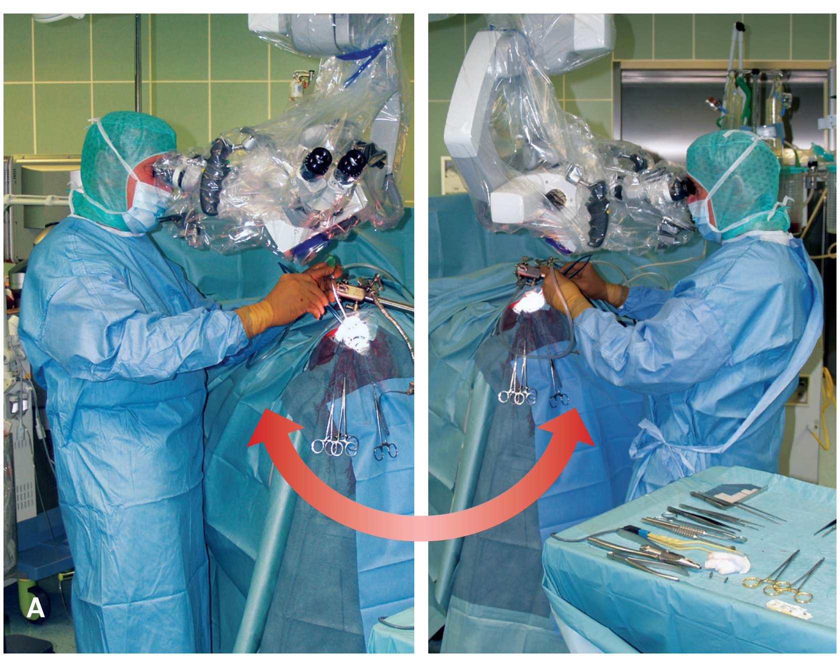


Fig. 1.0.22 *Frequent changes in the position of the operating microscope are necessary when visualizing extended deep-seated areas through a keyhole craniotomy. This offers a sector-like widening of the surgical field.*

Standing vs. sitting?

Basically, operating theater layout and patient positioning should offer a physiologically acceptable ergonomy for the surgeon, operating through a limited approach. However, surgical dissection through these limited keyhole craniotomies frequently requires changes in the surgeon's position when visualizing an extended intracranial area according to a sector-like widening of the surgical field (Fig. 1.0.22). In our experience, this "dancing around the table" is more relaxing for the surgeon while standing, even when performing long and time-consuming procedures. For this reason, we prefer to perform the entire surgical procedure in a standing position without the need for complicated, specially designed and therefore expensive operating chairs (Fig. 1.0.23).

Of course, the height of the operating table should be adjusted to avoid excessive bending of surgeon's body and neck; the optimal table height is usually at the level of surgeons elbow. However, it can be variable according to the focus distance of the microscope and to the specific case.



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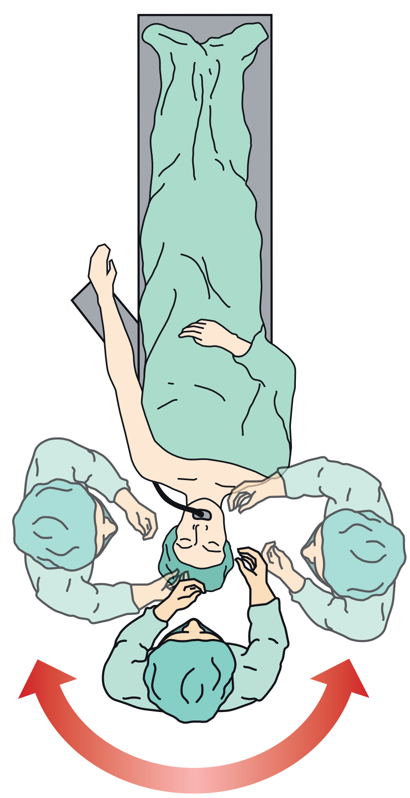


Fig. 1.0.23 *Frequent changes in position of the microscope mean that the surgeon also has to change position frequently as shown on the intraoperative photographs (A) and schematic drawing (B). However, in our experience, this "dancing around the table" while standing allows minimally invasive procedures to be performed in a more relaxed manner.*

Fig. 1.0.24 *Photographs from the operating theater illustrating the intraoperative use of a surgical microscope (A) and endoscope (B). Note the application of a Zeiss Pentero microscope (Carl Zeiss Surgical GmbH, Oberkochen, Germany) and highly sophisticated endoscopic equipment (Aesculap AG, Tuttlingen, Germany).*

The operating table

Present-generation operating tables allow adequate and safe positioning of the patient offering optimal surgical access of the target region without positioning-related risks. In addition, modern electric operating tables allow a great amount of variation in patient position during the procedure. Operating through limited approaches with frequent changes in the direction of surgical dissection, this possibility of intraoperative remodelling is especially significant.

The operating microscope, intraoperative use of endoscopes

The intraoperative use of microscopes is mandatory in keyhole neurosurgery. In our department, we prefer the Zeiss NC 4 and Zeiss Pentero microscopes (Carl Zeiss Surgical GmbH, Oberkochen, Germany), which allow perfect optical visualization with a high-quality digital photo and video documentation.

The operating microscope offers adequate magnification of the operative field in a stereoscopic manner and allows illumination of the surgical field. However, as above mentioned, the loss of light intensity in the deep-seated surgical field is a fundamental problem. For the purpose of bringing light into the site, operating microscopes can effectively be supplemented with the intraoperative use of modern endoscopes (Fig. 1.0.24).

The advantages of the endoscopic image are the increased light concentration, extended viewing angle and clear representation of anatomical details in a close-up position (Fig. 1.0.25).

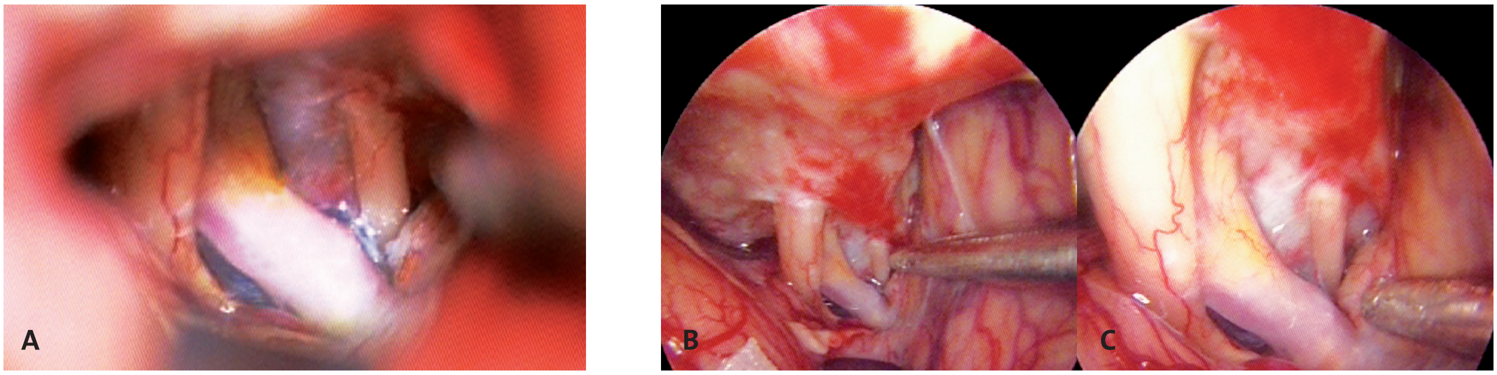


Fig. 1.0.25 *Intraoperative photographs showing exposure of the suprasellar area with the CN II, ICA and CN III through a right-sided supraorbital approach. Note the increased light intensity and extended viewing angle using a rigid endoscope (B) compared with the visualization of the surgical microscope (A). In close-up position, the endoscope gives a clear view of the anatomical details (C).*

The endoscope is especially ideal for obtaining a detailed view of structures in the shadow of the microscope beam. Thus, in situations during microsurgical dissection when additional visual information of the target area is desired or when avoidance of retraction of superficial structures is recommended, an endoscope is introduced into the surgical site. Both devices, microscope and endoscope, supplement each other due to their different optical properties.

Rigid lens scopes are recommended for *Endoscope-Assisted Microsurgery* (EAM) because only the position of instruments with rigid shafts can be controlled precisely and because, at present, only lens scopes offer acceptable image quality. Endoscopes with angled shafts are preferred for endoscope-assisted neurosurgery as the camera attached to the eyepiece does not interfere with the visual field of the microscope and does not disturb surgical manipulation (Figs. 1.0.26–30). Different degrees of inclination of the front lens offer different viewing angles of 0°, 30°, 45° and 70°. In addition, modern digital video technology is necessary to achieve full use of endoscope-assisted microsurgery.

Here it is important to notice that there are two different ways of performing endoscope-assisted techniques in keyhole neurosurgery. *Endoscope-Controlled Microneurosurgery* (ECM) offers endoscopic visualization of the surgical field according to a free-hand technique. In the case of limited visualization through the surgical microscope, the surgeon introduces the endoscope into the surgical site. For immediate optical control of the pathoanatomical situation, e.g., for allowing precise tumor removal or clip application, the endoscope is usually used only for a few minutes. The endoscope is grasped in one hand; in the other hand is a sucker for continuous cleaning of the scope (Fig. 1.0.26 A). Using pure *Endoscopic Microneurosurgey* (EM), the endoscope is fixed with a special holding device, offering bi-manual dissection under an endoscopic image. In this way, the "two-handed" surgeon is able to dissect without limitation in surgical manipulation. Without a microscope, the fixed endoscope is permanently used for a longer time during keyhole surgery (Fig. 1.0.26 B).

The use of endoscope-assisted technology in the course of microsurgical procedures with significantly improved visual control may contribute to the criteria of the keyhole concept with minimum iatrogenic trauma and maximum efficiency.

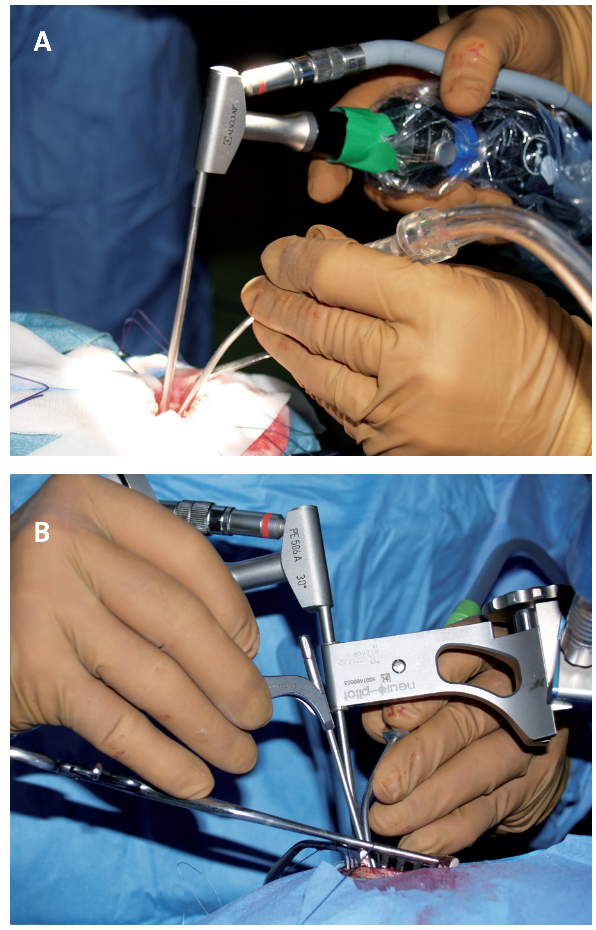


Fig. 1.0.26 *Intraoperative performance of endoscope-assisted microsurgery (EAM). Note the "one-handed" surgeon using an endoscope-controlled microneurosurgical technique (ECM). The endoscope is grasped in one hand, with the other hand a sucker is introduced for continuous cleaning of the tip of the endoscope (A). Using pure endoscopic microneurosurgery (EM), the endoscope is fixed in a special holding arm, allowing bi-manual dissection. The "two-handed" surgeon is able to work without limitation in surgical manipulation (B).*

Fig. 1.0.27 *Pure endoscopic microsurgical dissection using a holding arm, holding device and angled endoscope. The surgeon concentrates on the video-monitor; the highly sophisticated system allows free bi-manual surgical dissection without using a surgical microscope.*

Fig. 1.0.28 *Holding arm used for stable intraoperative fixation of the endoscope (UNITRAC arm, Aesculap AG, Tuttlingen, Germany).*

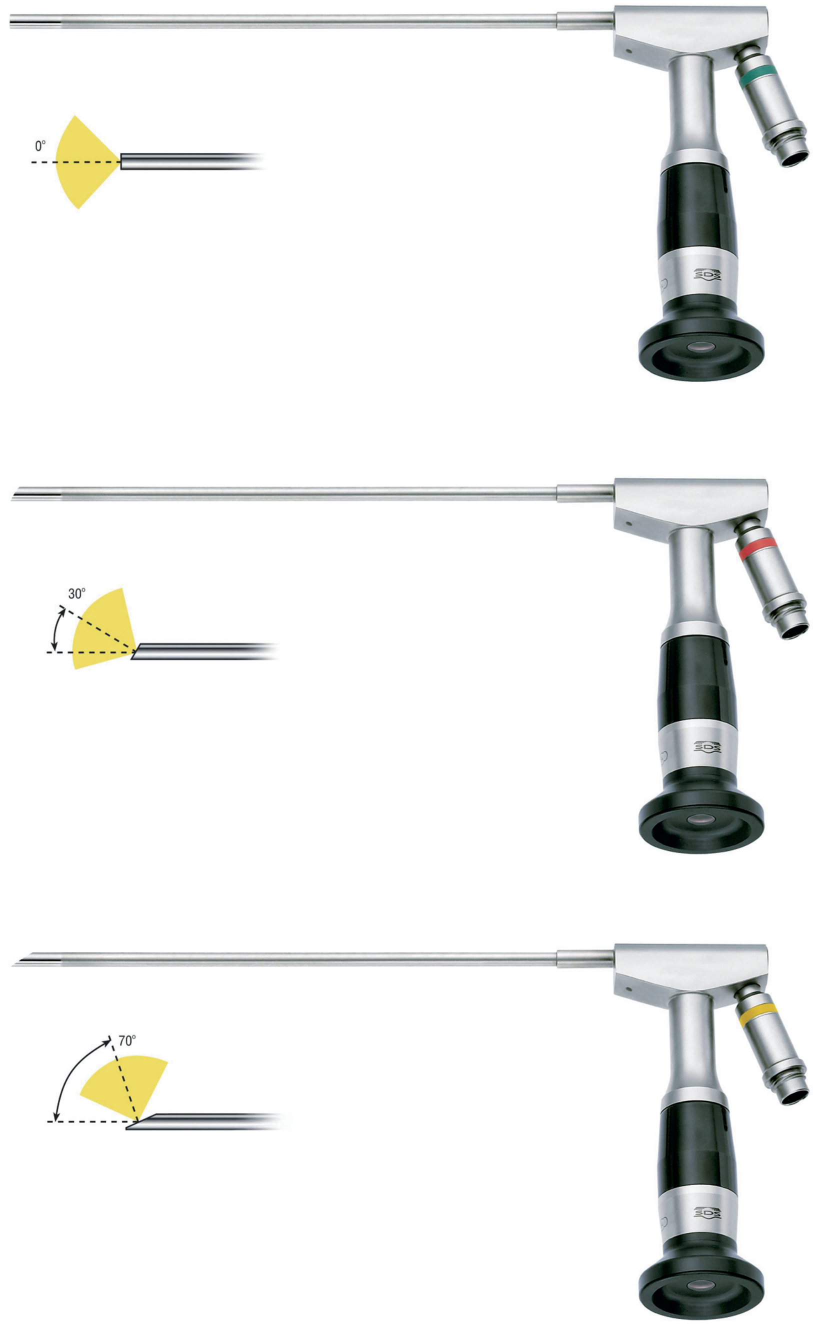


Fig. 1.0.29 *Rigid lens endosopes with 0°, 30° and 70° viewing angles, especially considered for endoscope-assisted microneurosurgery (Aesculap AG, Tuttlingen, Germany). Note the angled shaft of the tools, allowing free surgical manipulation around and along the endoscope.*

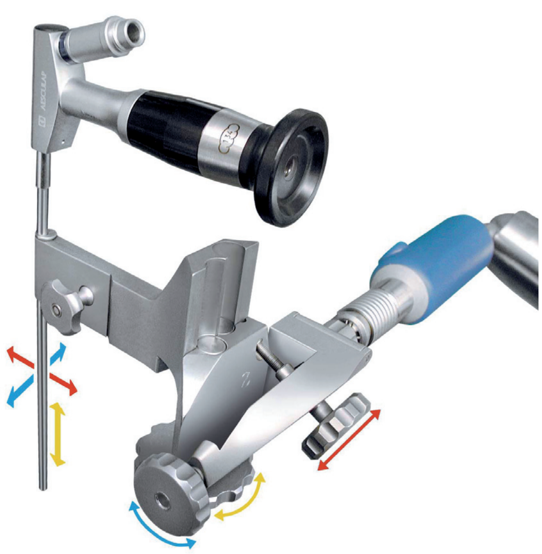


Fig. 1.0.30 *Specially designed endoscope holding device (Neuro-Pilot, Aesculap AG, Tuttlingen, Germany). The system offers adequate fixation, and the position of the endoscope can be mechanically remodelled with precise driving wheels (note blue, red and yellow arrows).*

Microsurgical instruments
The use of microneurosurgical instruments is obligatory in treating intracranial lesions. Highly sophisticated instrumentation including self-retaining retractors, microdrills, Kerrison micropunches, suction tubes, fine bipolar forceps, microscissors, diamond knives, diamond hooks, microforceps, microdissectors, microcurettes, and clip appliers allows adequate microsurgical dissection under microscopic or endoscopic control.

Nevertheless, when approaching deep-seated areas through a limited craniotomy with a diameter of ca. 15 to 20 mm, the intraoperative use of conventional microinstruments may be a problem because of the narrow surgical corridor. For example, a bipolar forceps or a microscissor will be closed at its tip when the target is reached because it has already been pushed together by the edges of the small craniotomy opening. For this reason as previously described, the invention and intraoperative use of recently developed microinstuments is mandatory for keyhole surgery.

Keyhole microinstruments are specially designed with a tube shaft allowing unhindered introduction of the tool through the limited craniotomy (Fig. 1.0.31). Tube-shaft instruments can be used in a much reduced operating corridor offering safe manipulation within the narrow surgical corridor and obvious visualization of the surgical field. By noticing that usually only the last 2–3 millimeters of a scissor blade are actually used, their blade size was hence reduced producing improved vision, range of motion and access. In several cases, the application of tube-shaft microinstruments is obligatory when operating through keyhole approaches (Figs. 1.0.32, 1.0.33).

Keyhole instruments should be carefully cleaned at the end of the operation, protecting sharp tips, and kept in special trays that separate the different types of instruments. Careful handling by the operating theater staff can eliminate the wear and tear of sensitive microdevices.

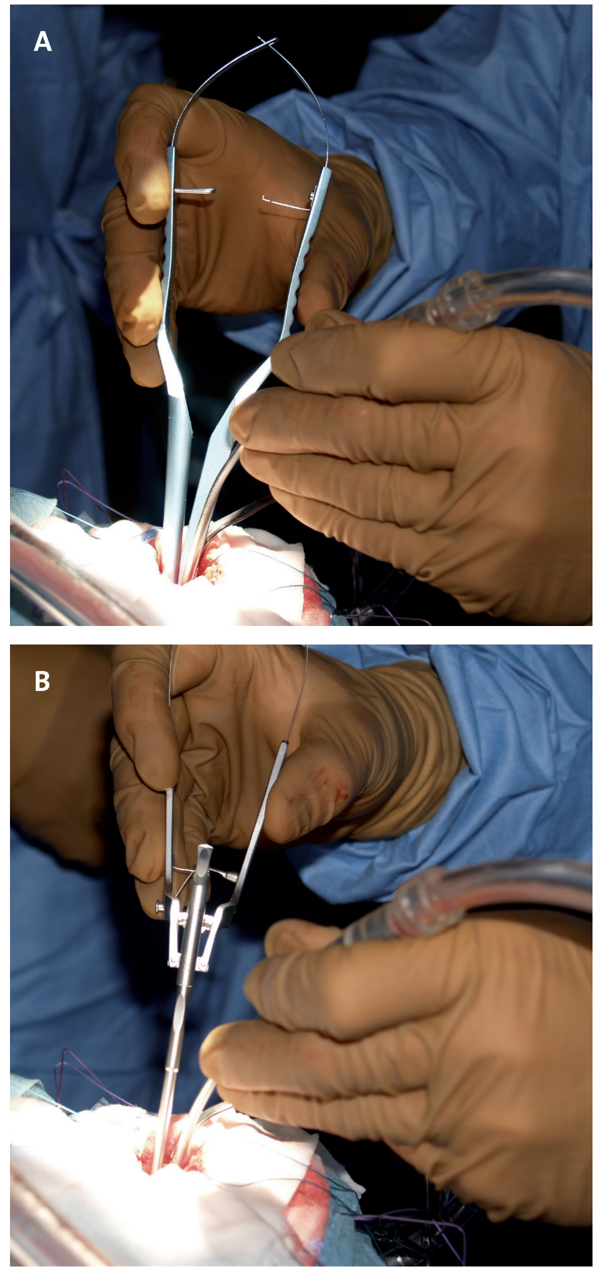


Fig. 1.0.31 *Intraoperative use of a conventional bayonet-shaped clip applier (A) compared with a tube-shaft device (B). Note that the conventional microinstruments require significantly more space within the narrow surgical corridor. Tube-shaft keyhole instruments are designed especially for unhindered introduction of the tool through the limited craniotomy.*

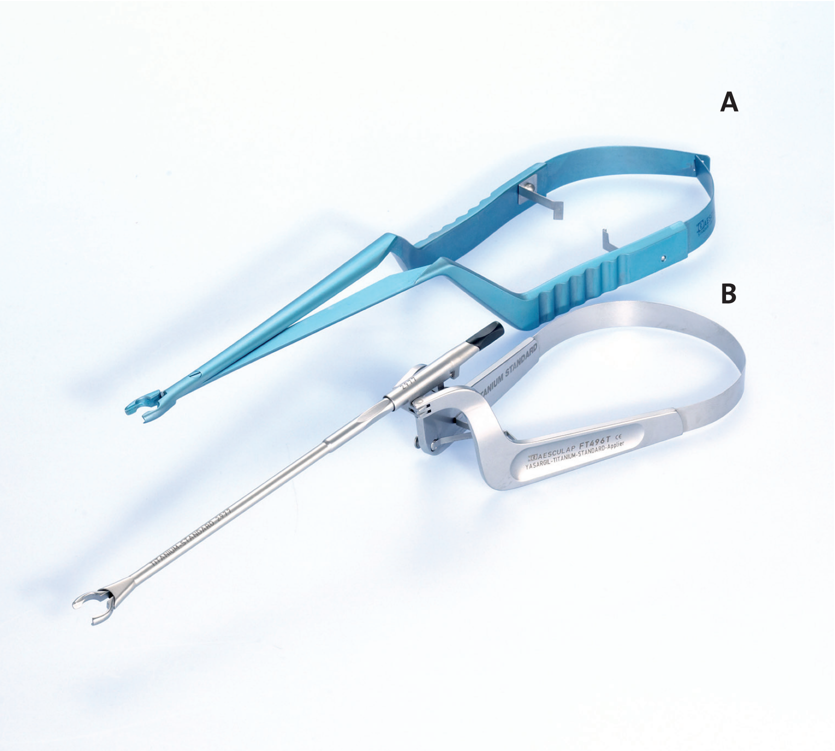


Fig. 1.0.32 *Photograph showing a conventional bayonet-shaped clip applier (A) and a tube-shaft instrument (B) especially considered for minimally invasive keyhole neurosurgery. Using limited craniotomies with a diameter of ca. 15–20 mm, tube-shaft instruments allow unhindered visualization of the deep-seated site and safe manipulation within the narrow surgical corridor.*

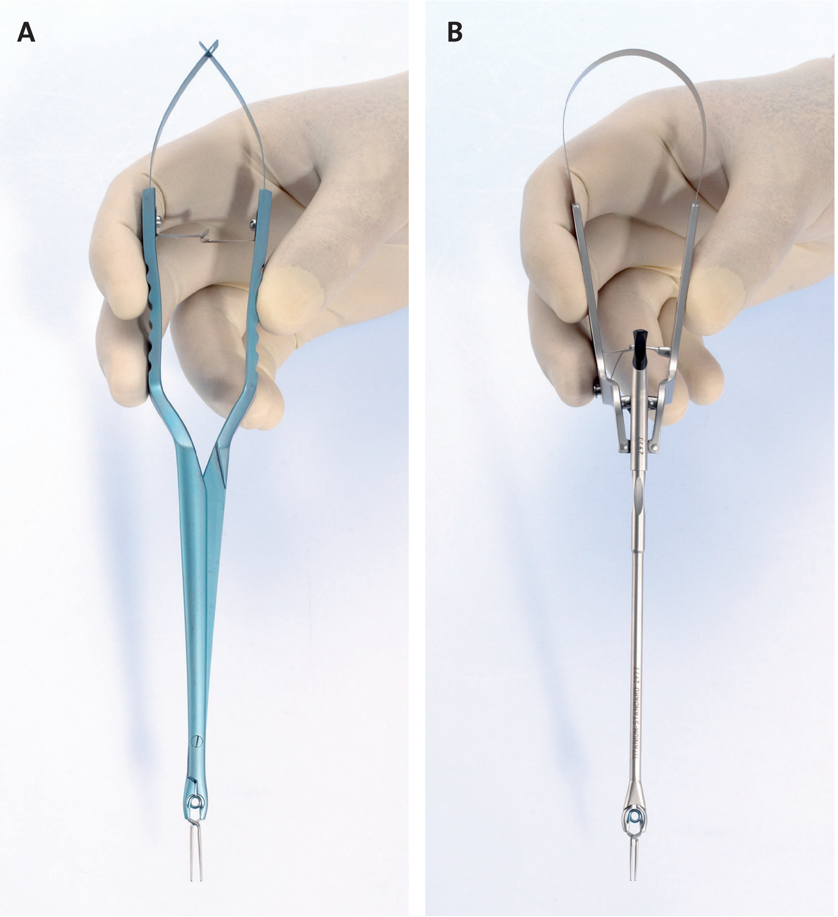


Fig. 1.0.33 *Comparison of a conventional (A) and a tube-shaft (B) clip applier showing impressively the difference in instrument design. When operating through keyhole craniotomies, the use of tube-shaft instruments is often obligatory for safe intraoperative dissection.*

Performance and technique of keyhole neurosurgery

Preoperative planning

The goal of preoperative planning is to choose the correct and accurate way, operating with a minimum of iatrogenic trauma and achieving a maximum of surgical efficiency without missing the target or causing injury to sensitive intracranial structures.

The planning and execution of the approach play a critical role in performing minimally invasive keyhole approaches. The smaller the craniotomy the greater the need for precise planning and self-made completion of the approach because the corridor of surgical dissection cannot be changed during the procedure.

The preoperative planning is based on the precise and particular anatomical knowledge of the target region and on a careful preoperative study of diagnostic images. Not only the diagnosis gains a principal interest, the task of modern neuroradiology should not end with the definition of the suspected pathology. The goal is to describe additional information concerning anatomical details, not only of the lesion itself but of its vicinity and of neighboring bony, dural, nervous and vascular structures. Using the excellent diagnostic facilities of CT, MRI and digital subtraction angiography (DSA), one has today the possibility to demonstrate the special anatomical situation of the patient including small details and elucidate preoperatively the precise individual anatomy and pathology. It is especially important to determine anatomical windows of the subarachnoidal spaces that provide access to the pathological processes. These anatomical paths for surgical dissection should be described preoperatively and be included in the planning of the surgical procedure. According to these windows and surgical paths, the least traumatizing approach to the target region should be defined, which helps to avoid retraction and unnecessary surface exploration.

Computers have been used increasingly to help surgeons to analyze preoperative imaging data. Various computer programs have been developed to generate three-dimensional representations of tomographic imaging data in order to plan neurosurgical approaches and most nowadays available image guidance systems offer surgical planning tools. Conceptually, the planning of a surgical procedure with three-dimensional computer-generated

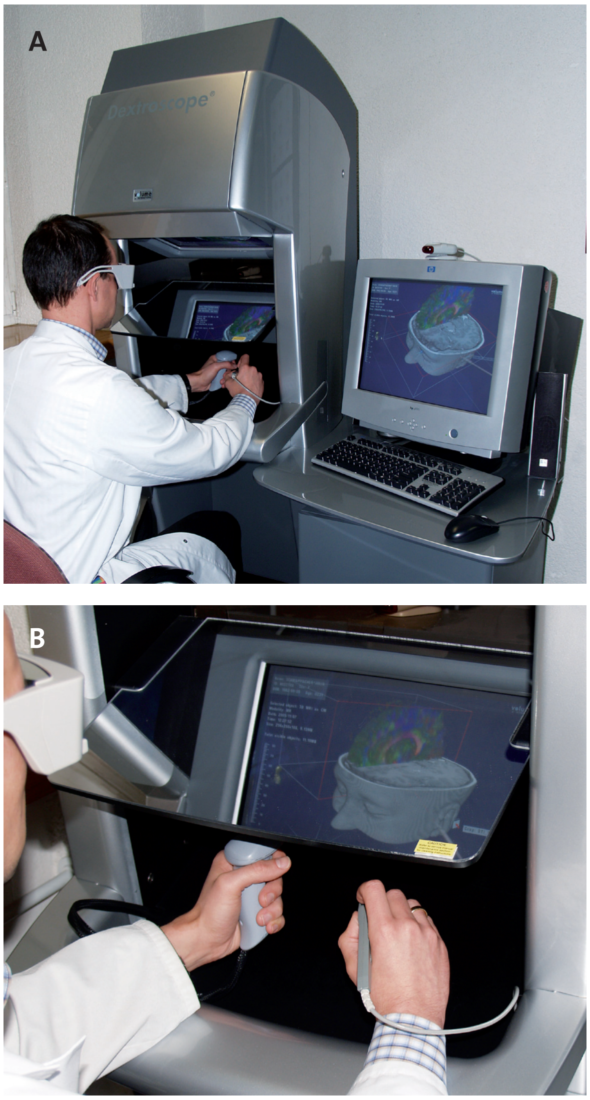


Fig. 1.0.34 *Computer analysis of the preoperative imaging data with three-dimensional representation of the pathoanatomical situation offers a useful tool for planning of the surgical approach. Photograph shows the application of the Dextroscope (Volume Interactions Pte. Ltd., Singapore), for which liquid display shutter glasses are worn (A). The user works with both hands inside the stereoscopic virtual workspace; one hand holds an ergonomically designed handle to move the three-dimensional data, the other hand holds a pen-shaped instrument which can be used to perform detailed data manipulations (B).*

data should reflect the three-dimensionality of the real procedure. In our department, we use the Dextroscope system (Volume Interactions Pte. Ltd., Singapore), which allows a stereoscopic display of the preoperative data and virtual manipulation with three-dimensional tools instead of mouse and keyboard (Fig. 1.0.34).

In the Dextroscope, the user works with both hands inside a stereoscopic virtual workspace. This is achieved by reflecting a computer-generated 3-D scenario via a mirror into the user's eyes. Wearing liquid display shutter glasses synchronized with the time split display, the user reaches with both hands behind the mirror into the "floating" 3-D data. Electromagnetic sensors in both hands convey the interaction and allow manipulation of the 3-D data in real time. One hand holds an ergonomically shaped handle to move the 3-D data freely as if it were an object held in real space. The other hand holds a pen-shaped instrument which appears inside the virtual reality workspace as a computer-generated instrument and which can be used to perform detailed data manipulations (Fig. 1.0.34B).

With the three-dimensional individual anatomical details of a specific patient, it is possible to perform a specific and tailored surgical procedure reducing the surgical traumatization to a necessary minimum limit.

In this way, preoperative planning is the most important part of the minimally invasive and maximally effective keyhole neurosurgery.

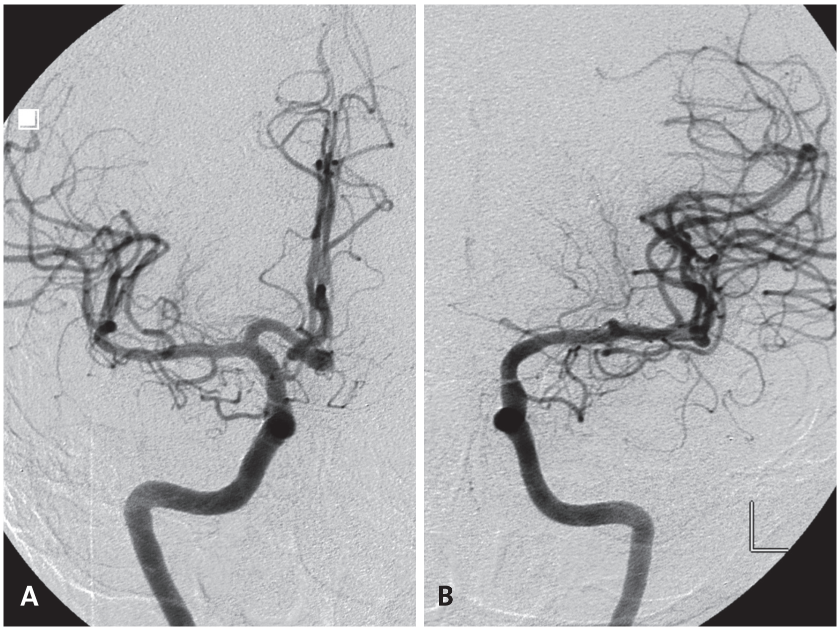
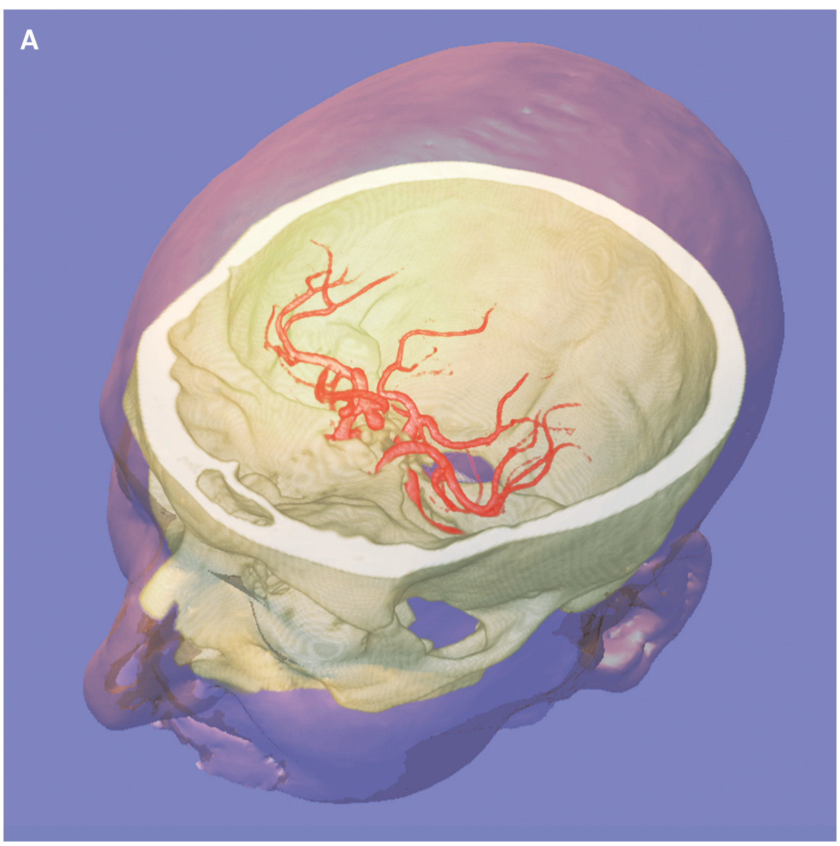


Fig. 1.0.35 A, B *Illustrative case of a patient with an unruptured aneurysm of the ACoA. Conventional DSA of the right (A) and left (B) carotid arteries in antero-posterior view demonstrates the aneurysm, with the dome directed to left. Note that the A1 segment of the left ACA appears hypoplastic, making interventional therapy with reconstruction of the ACoA more difficult.*

Fig. 1.0.35 C *3-D angiography of the right ICA showing the neck region and the dome of the aneurysm, directed to the left side.*



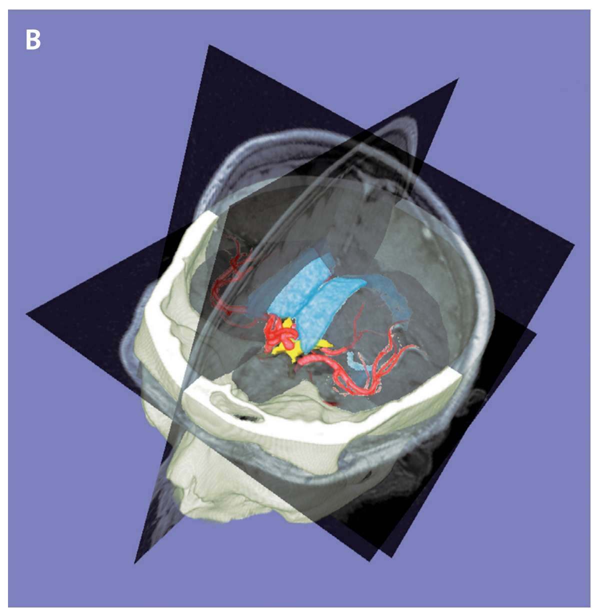


Fig. 1.0.36 *Three-dimensional dextroscope reconstruction of the preoperative CT and MRI data showing the skull base structures, vessels of the anterior circulation with the ACoA aneurysm, and important anatomical structures of the neighborhoods. Note the relationship of the vessels to the appearance of the skin surface (A) and to the triplanar MR imaging (B).*

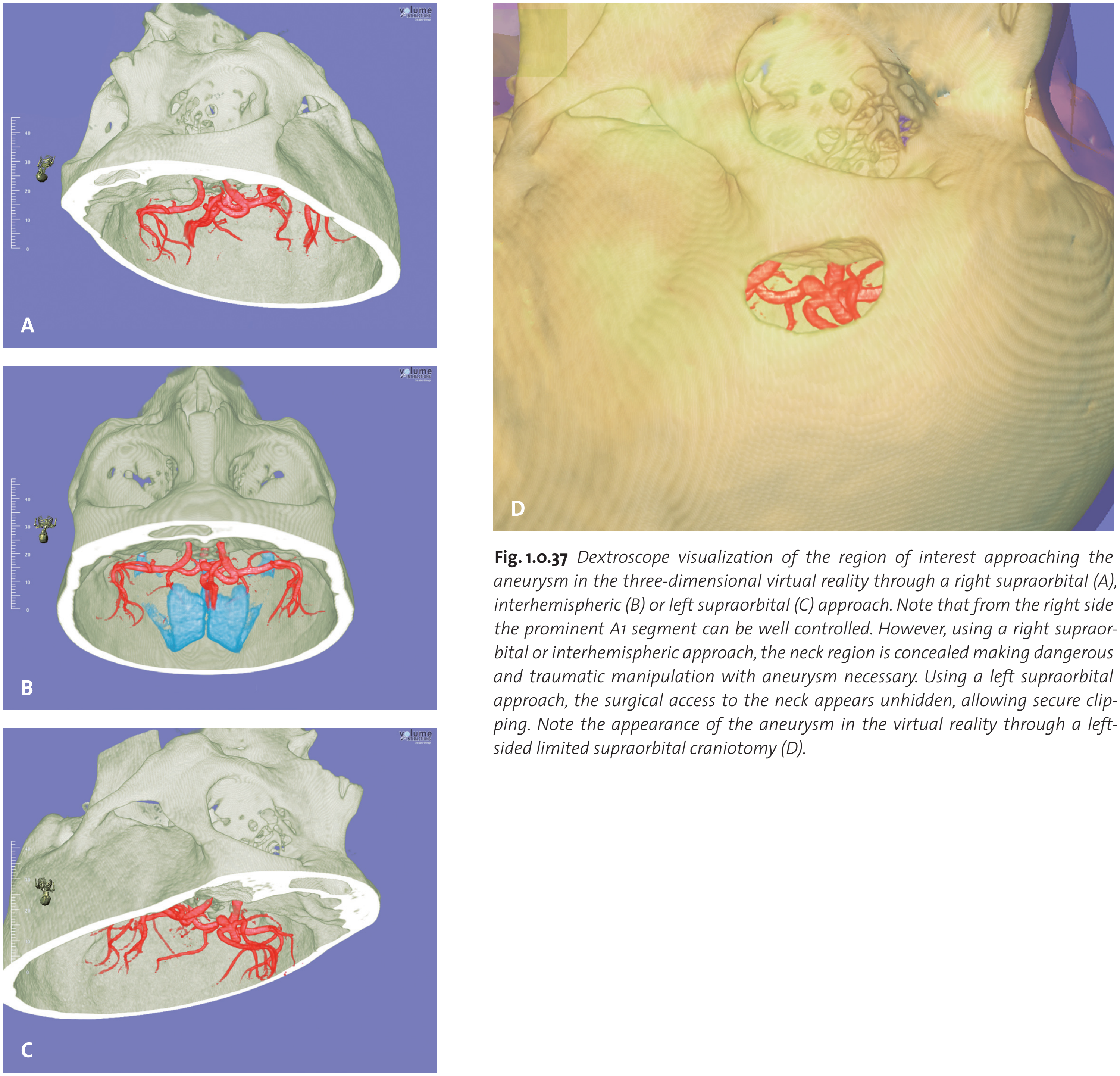


Fig. 1.0.37 *Dextroscope visualization of the region of interest approaching the aneurysm in the three-dimensional virtual reality through a right supraorbital (A), interhemispheric (B) or left supraorbital (C) approach. Note that from the right side the prominent A1 segment can be well controlled. However, using a right supraorbital or interhemispheric approach, the neck region is concealed making dangerous and traumatic manipulation with aneurysm necessary. Using a left supraorbital approach, the surgical access to the neck appears unhidden, allowing secure clipping. Note the appearance of the aneurysm in the virtual reality through a left-sided limited supraorbital craniotomy (D).*

Patient positioning

The neurosurgeon must plan and perform the proper positioning of the patient's body and head himself before starting the surgical procedure. This self-made preparation including planning and positioning is essential for creating keyhole craniotomies. The goal of patient positioning is to achieve optimal surgical access to the target region without positioning-related dangers for the patient. In addition, position should offer ergonomic conditions for the surgeon and make the operation physiologically acceptable during the often long, time-consuming procedures. The use of a modern operating table, which can be manipulated electrically, also facilitates optimal patient positioning during surgery (Fig. 1.0.38).

Almost every intracranial target region can be successfully approached using the supine or prone position. In our opinion, making use of complex positioning techniques, e.g., the lateral park bench position, semiprone position, sitting or semisitting position, does not offer additional advantages in intracranial visualization. Surgical approaches performed using these complicated, time-consuming positioning maneuvres can be done equally well with the patient in the simple supine or prone position. In addition, particularly the sitting and semisitting positions cause several surgical and anesthesiological disadvantages and make the operation physiologically very difficult for the surgeon.

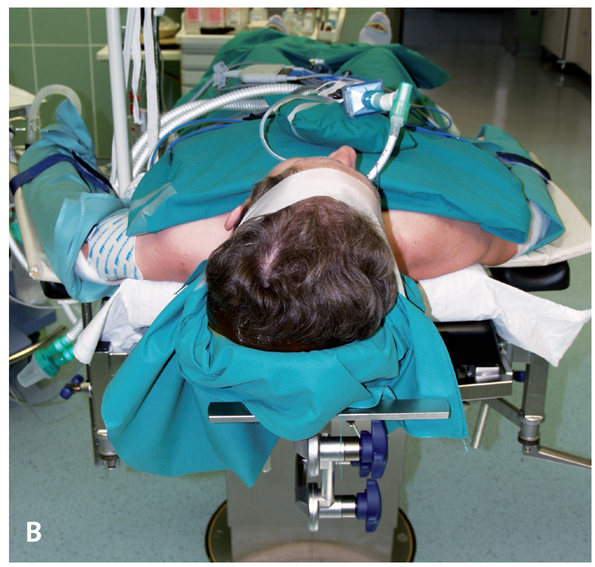


Fig. 1.0.38 *Supine positioning of the patient prepared for supraorbital craniomy using a modern operating table. The head is secured in a three-pin clamp (A). In several cases, the use of skull clamps is not necessary, offering a simple and brief preparation of the patient. The head is positioned in a soft cushion and fixed with a simple tape (B).*

The supine position

The majority of neurosurgical operations take place with the patient in the supine position (Figs. 1.0.38, 1.0.39). This position enables the surgeon to access the anterior and middle cranial fossa, the frontal and temporal skull base and the cerebellopontine region.

Approaching these target regions, other neurosurgeons frequently use the lateral park bench position. However, the lateral position is time-consuming and difficult to use for an inexperienced surgical team without adversely affecting pressure points. Using the simple supine position, the patient is placed on the table, well padded but with the shoulder some centimeters above the edge of the table; the ipsilateral shoulder can be elevated with a cushion to facilitate the head rotation. In several cases, the use of skull clamps is not necessary, offering simple and brief preparation of the patient (Fig. 1.0.38 B). If used, the single pin of the head fixator should be placed in the opposite frontal area behind the hairline to allow free manipulation of the ipsilateral side during the procedure. The pin

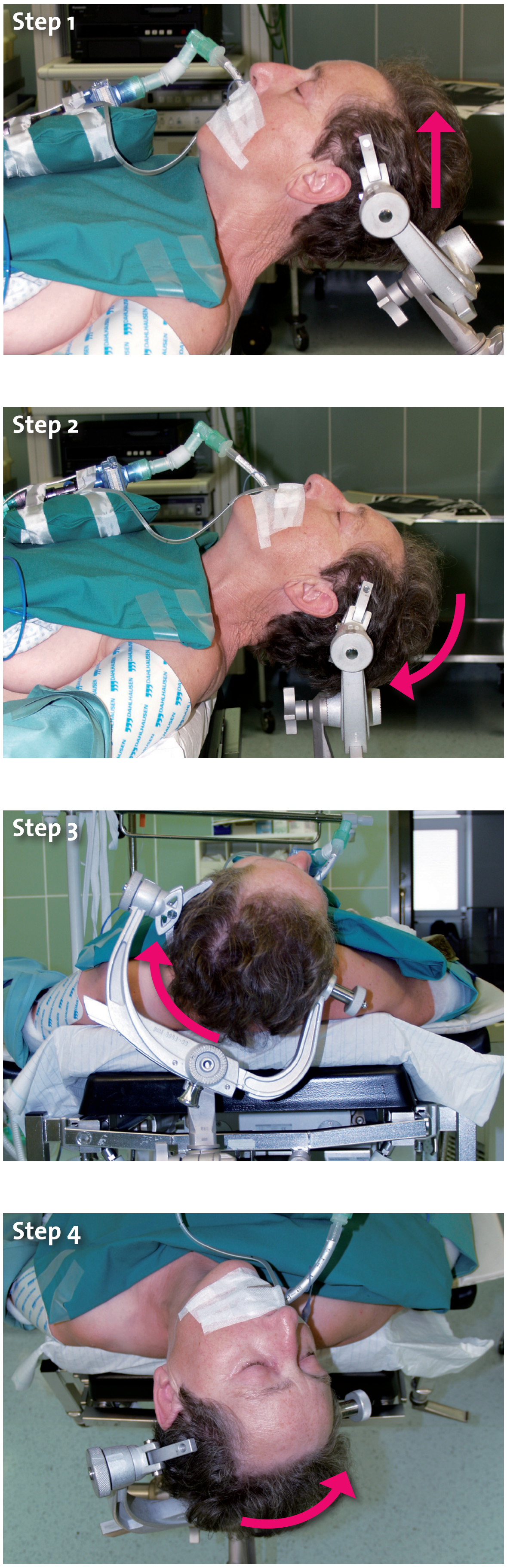


Fig. 1.0.39 *Approaching the frontal skull base, and the anterior or middle cranial fossa through a subfrontal supraorbital approach, the next steps of positioning should be followed:*

Step 1. *Initially, the head is elevated above the level of the thorax to facilitate venous drainage of the intracranial space. In addition, elevation offers effective decompression of the main cervical vessels, larynx and the ventilation tube.*

Step 2. *As a second step, the head should be retroflected ca. 15°. This gentle retroflexion supports not only gravity-related self-retraction of the frontal or temporal lobe, but also depends upon the precise anatomical and pathological situation. Generally, lesions with close proximity to the skull base require less retroflexion; structures situated more cranially can be optimally approached with more head retroflexion.*

Step 3. *Thereafter, the head is rotated according to the target region. Performing a supraorbital approach through an eyebrow skin incision, the ipsilateral temporomesial area and Sylvian fissure can be best approached with a rotation of ca. 15°. Approaching the lateral suprasellar and retrosellar area, a rotation of ca. 20° is necessary. For the anterior suprasellar region, a rotation of 30° and for the olfactory groove, a 45° to 60° rotation is required. By choosing the correct angle between 30° and 60°, one can also make contralateral lesions visible. Note that right-handed surgeons using a left-sided craniotomy need more rotation to provide an efficient working position.*

Step 4. *The last positioning step using the supraorbital approach is lateroflexion of ca. 10°, providing an ergonomic working position during surgery.*

should not be placed into the temporalis muscle as this diminishes the stability of the system (Figs. 1.0.38 A, 1.0.39).

The prone position

The prone position is best for the torcular region, pineal region, midline posterior fossa and the craniocervical junction.

Some outstanding neurosurgeons still use the sitting or semisitting position to approach the same target regions. As a main advantage, the sitting position improves venous drainage of the posterior fossa. Blood, CSF and irrigating fluids drain away from operative site making viewing of the anatomy easier. However, the sitting position requires enormous anesthesiological monitoring because of the danger of air embolism and cardiopulmonary instability. In addition, severe pneumocephalus or ventricular collapse because of the large loss of CSF can appear as postoperative surgical complications.

In our department, we utilize the prone position for the above mentioned target regions. Advantages of this positioning are the simplicity of the technique and comfort for the patient undergoing long, time-consuming procedures. In addition, the perpendicular direction of surgical dissection provides an ergonomic working position for the surgeon with optimal visualization of the operating field. The patient's shoulder and hips must be well supported by heavy rolls. The head is placed in pins allowing optimum positioning. We do not require the use of a horseshoe headrest to avoid severe compression of the skin during long surgical procedures.

Orientation according to anatomical landmarks

After preoperative planning of the approach according to the individual pathoanatomical situation and after patient positioning according to the target region, the placement and size of the craniotomy should be individually tailored (Fig. 1.0.40).

For this reason, palpable structures of the patient's anatomical surface should be determined and drawn on the skin with sterile markers (A). For example, when using the supraorbital craniotomy, the important anatomical landmarks of the frontotemporal osseous skull, such as the supraorbital foramen (1), temporal line (2), frontobasis with impression of the Sylvian fissure (3) and the zygomatic arch (4) are palpated precisely. Special attention must be given to the course of the superficial neurovascular structures of the frontotemporal region such as the supraorbital nerves and artery (5) and the frontal branch of the facial nerve (6). Only thereafter should the borders of the craniotomy be marked, taking into consideration the position of the lesion and the landmarks drawn on the skin (B). After defining the craniotomy, the individual optimum line of the skin incision is marked with the pen (C).

Recently, the optimal placement of the craniotomy can be effectively controlled with the use of modern navigation tools. However, the approach must be determined after surgical orientation according to the accurate anatomical knowledge and the navigation device should play only the role of a precise control!

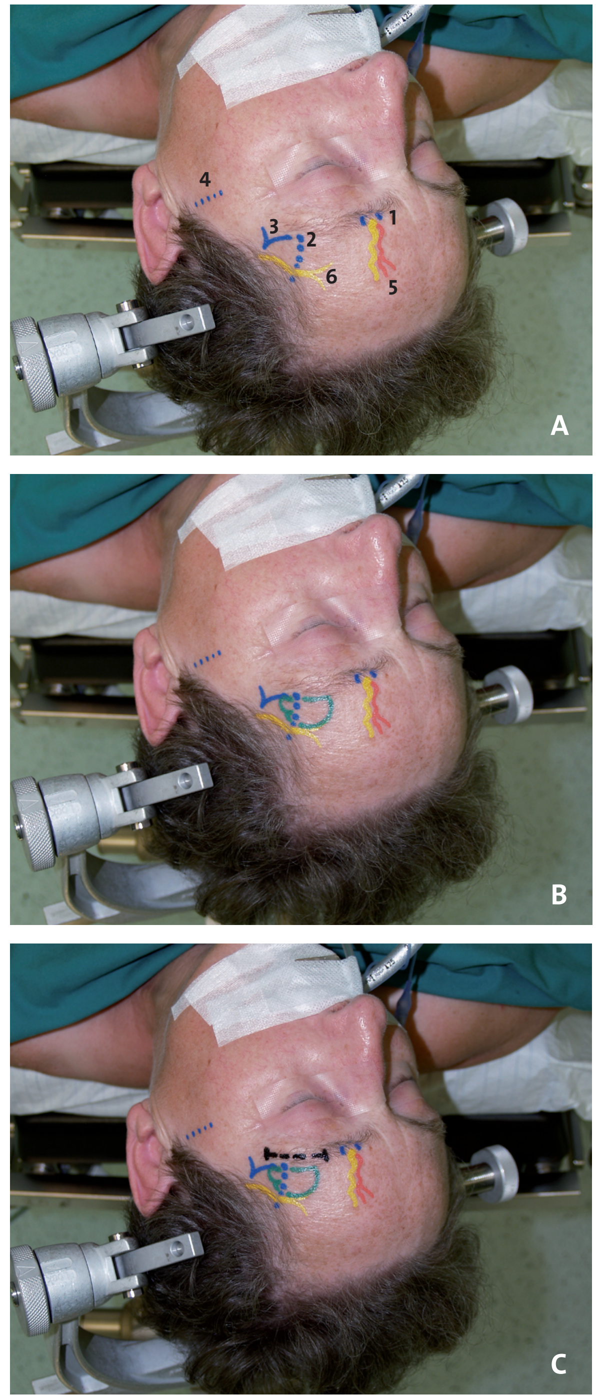


Fig. 1.0.40 *Illustrative case performing supraorbital craniotomy. For the appropriate skin incision, the important anatomical landmarks (A) of the osseous skull are palpated precisely and marked with a sterile pen (blue lines). Special attention must be given to the course of the superficial neurovascular structures of the frontotemporal region (yellow and red lines). Only thereafter should the borders of the craniotomy be marked (green line), taking into consideration the position of the lesion and the landmarks drawn on the skin (B). After defining the craniotomy, the individual, optimum line of the skin incision is marked with a black pen (C).*

Surgical dissection

Skin incision and soft tissue dissection

The skin incision is made according to the preoperative planning and anatomical orientation. The dissection should offer adequate inspection of the osseous surface whilst minimizing soft tissue trauma. An additional important factor is to achieve cosmetically favorable postoperative results with subsequent satisfaction among patients (Steps 1–3, Figs. 1.0.41–43).

Performing a supraorbital craniotomy through an eyebrow skin incision, shaving of the eyebrow is not necessary; for a pleasing cosmetic outcome, the incision line must be placed exactly in the haired area. Performing an approach within the haired area, we usually use a minimal 10 mm shaving according to the exact line of the skin incision.

Craniotomy, dural opening

The aim of keyhole neurosurgery is not the limited craniotomy, but the limited brain exploration and minimal brain retraction. In this way, the limited craniotomy is not the goal but the result of the philosophy of minimal invasiveness in neurosurgery.

After performing a limited keyhole craniotomy, removal of the inner edge of the craniotomy under protection of the dura can be very helpful. Careful drilling of this inner bone edge significantly increases the angle for visualization and manipulation; small osseous extensions of the skull base should also be carefully removed to provide an excellent overview and to allow free microsurgical access to deep-seated sites. These maneuvres greatly facilitate the use of the operating microscope and microsurgical instruments in the further course of the operation (Steps 4–7, Figs. 1.0.44–47).

The dural opening should offer optimal intracranial exposure and facilitate the dural closure thereafter. The dura should be opened in a curved or "Y" shaped fashion with its base toward to the skull base or to the midline. The free dural flap is fixed with sutures; other dural elevation sutures are not required (Step 8, Fig. 1.0.48).

Intradural dissection

The intracranial dissection should be performed after exact planning of every step of the procedure. The surgeon should be able to "run through" each step of the operation in his or her mind according to mandatory anatomical and surgical experience. This offers safe manipulation within the surgical field and will help to prevent intraoperative complications.

First step of the intracranial procedure should be the sufficient drainage of CSF. Due to the marked intracranial relaxation, cortical retraction can be effectively minimized. With full employment of techniques such as endoscope-assisted keyhole microneurosurgery the intracranial procedure can be successfully completed (Steps 9–15, Figs. 1.0.49–55).

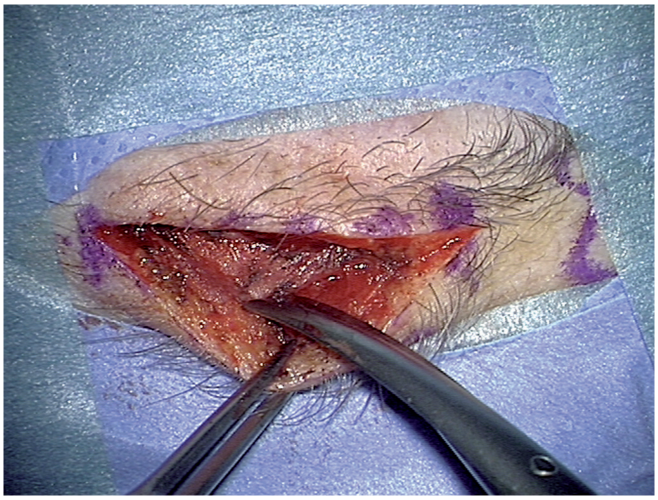


Fig. 1.0.41

Step 1

The skin incision begins laterally from the supraorbital incisura and is made within the eyebrow. For a cosmetically optimal result, the incision should follow the orbital rim. Note careful dissection of the skin flap using non-damaging forceps. The subcutaneous tissue is dissected upwards in a frontal direction to achieve optimal exposure; however, the skin flap should be gently mobilized downwards in an orbital direction to avoid periorbital hematoma (Fig. 1.0.41).

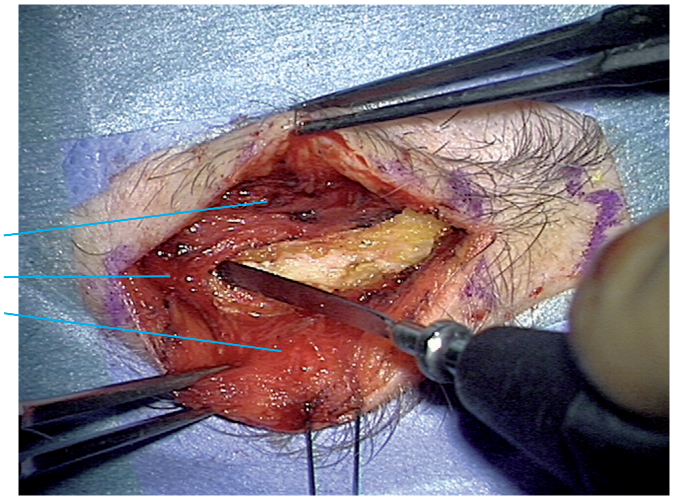


Fig. 1.0.42

Step 2

After skin incision, the skin flap is temporarily retracted with stitches exposing the frontal belly of the occipitofrontal muscle, the orbicular and the temporal muscles. The frontal muscles are cut with a monopolar electrode knife parallel to the glabella and the temporal muscle is stripped from its bony insertion. Note that the skin flaps are touched only with atraumatic forceps (Fig. 1.0.42).

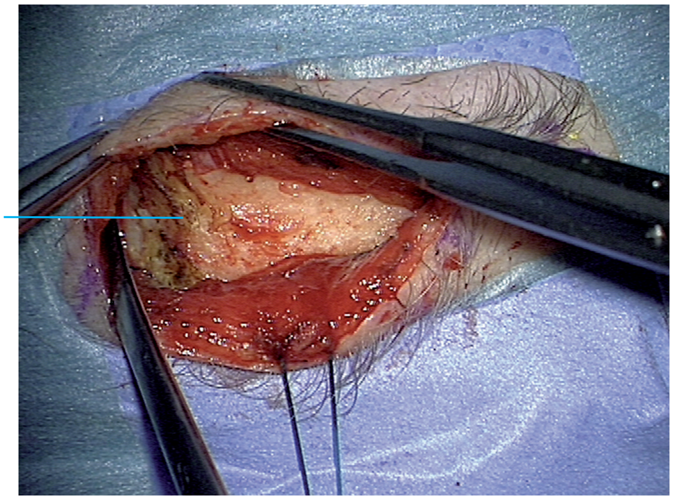


Fig. 1.0.43

Step 3

The temporal muscle is mobilized laterally using a blunt dissector. Note that exposure and mobilization of the temporal muscle should be restricted to the necessary minimum to prevent postoperative problems with chewing and later temporal atrophy. Note the temporal line; the dissector points to the level of the anterior skull base (Fig. 1.0.43).

Step 4
The temporal muscle is retracted with small wound hooks and the frontal muscle upwards and downwards with strong sutures allowing limited exposure of the supraorbital bony surface. Note that the frontal and orbicular muscles should be gently pushed downwards to the orbit. Careful dissection and minimal retraction of this muscular layer is essential to avoid postoperative periorbital hematoma. Using a high-speed drill, a single frontobasal burr hole is drilled posterior to the temporal line at the level of the frontal skull base (Fig. 1.0.44).

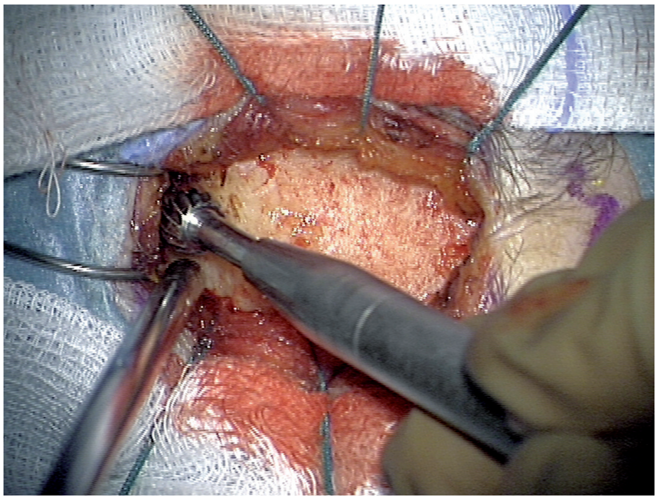


Fig. 1.0.44

Step 5
After minimal enlargement of the hole with fine punches and mobilization of the dura, a straight line is cut with a high-speed craniotome parallel to the glabella in a lateral to medial direction, taking into account the lateral border of the frontal paranasal sinus (Fig. 1.0.45).

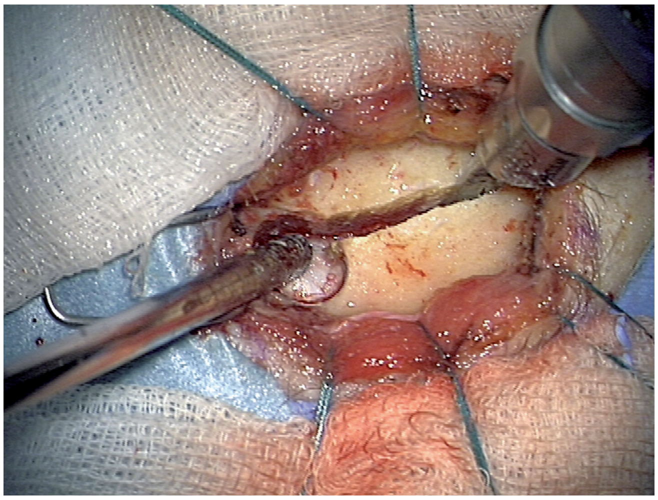


Fig. 1.0.45

Step 6
Thereafter a "C" shaped line is cut from the burr hole to the medial border of the previously cut frontobasal line, thus creating a bone flap with a width of ca. 15–20 mm and a frontal extension of ca. 10–15 mm (Fig. 1.0.46).

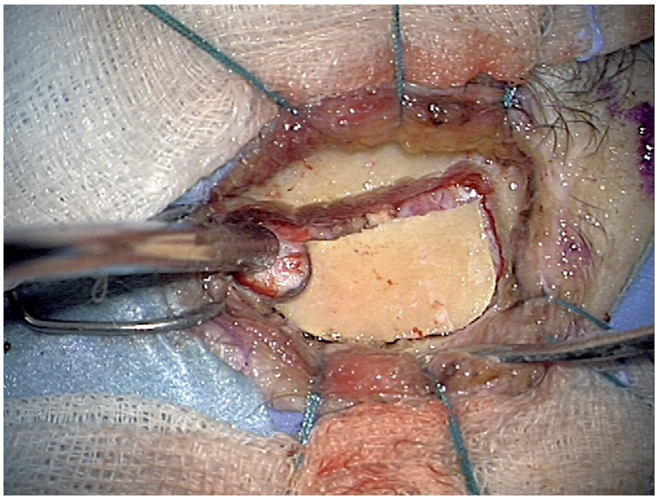


Fig. 1.0.46

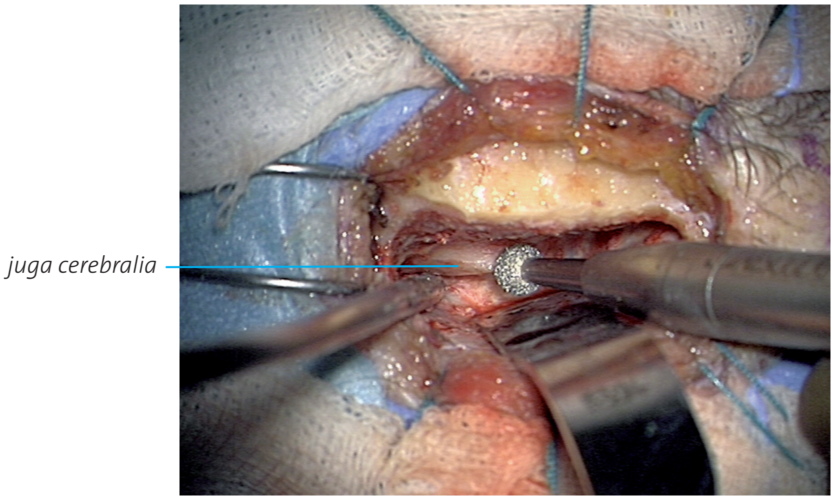


Fig. 1.0.47

Step 7

A very important stage of the craniotomy after removal of the bone flap is the high-speed drilling of the inner edge of the bone above the orbital rim under protection of the dura. Careful removal of this inner bone edge can significantly increase the angle for visualization and manipulation. Small osseous extensions of the superficial orbital roof, the so-called juga cerebralia, should also be drilled extradurally to obtain optimal intradural visualization. A small diamond drill is recommended. Note the application of a spatula for protection of the dural surface (Fig. 1.0.47).

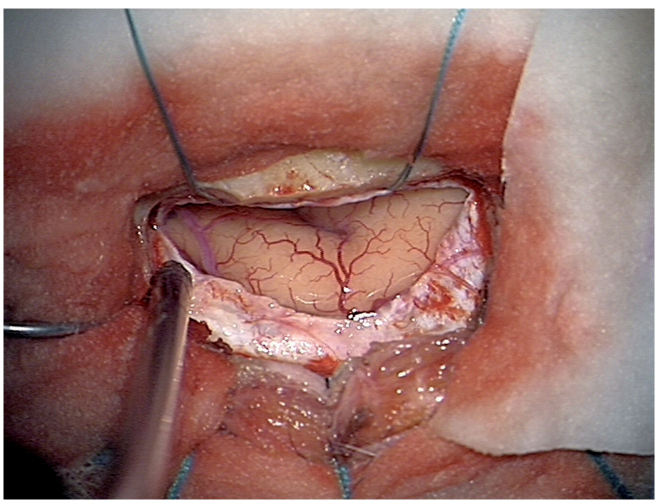


Fig. 1.0.48

Step 8

The dura should be opened in a curved fashion with its base toward to the supraorbital rim. The free dural flap is fixed downwards with sutures; other dural elevation sutures are not required (Fig. 1.0.48).

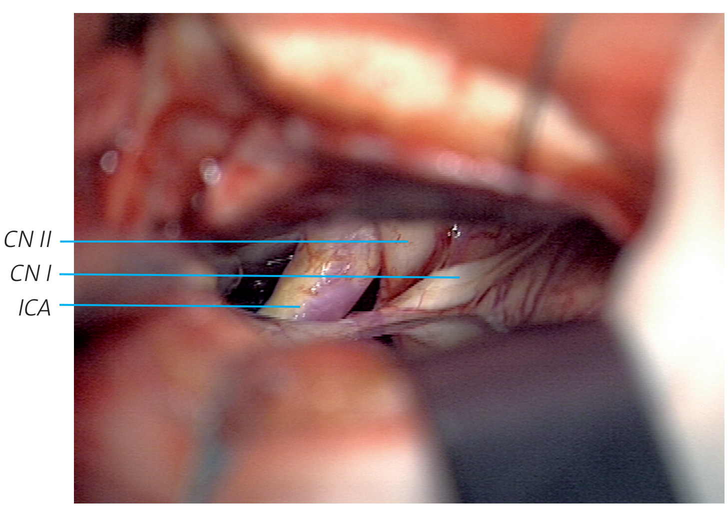


Fig. 1.0.49

Step 9

After opening the dura mater, the first step should be the sufficient drainage of CSF by opening the chiasmatic and carotid cisterns. After dissection of the arachnoid membranes, the anterolateral structures of the suprasellar region are exposed: the left CN I, CN II and the supraclinoid segment of the ICA. The frontal lobe is minimally retracted and the OPCA window is opened (Fig. 1.0.49).

Step 10

A 0° endoscope is introduced into the surgical field. Note the increased light intensity and the highly broadened observational field (A). In a close-up position (B), the anatomical details can be visualized and the deep-seated basilar bifurcation appears through the OPCA window (Fig. 1.0.50).

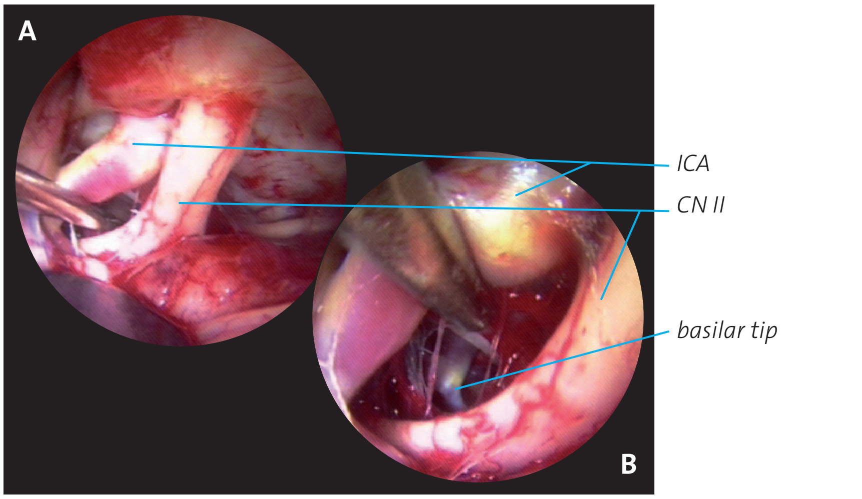


Fig. 1.0.50

Step 11

Dissecting to the midline, the aneurysm is approached. Note the lamina terminalis and a frontobasal branch of the ACA, adherent with the aneurysm sack (Fig. 1.0.51).

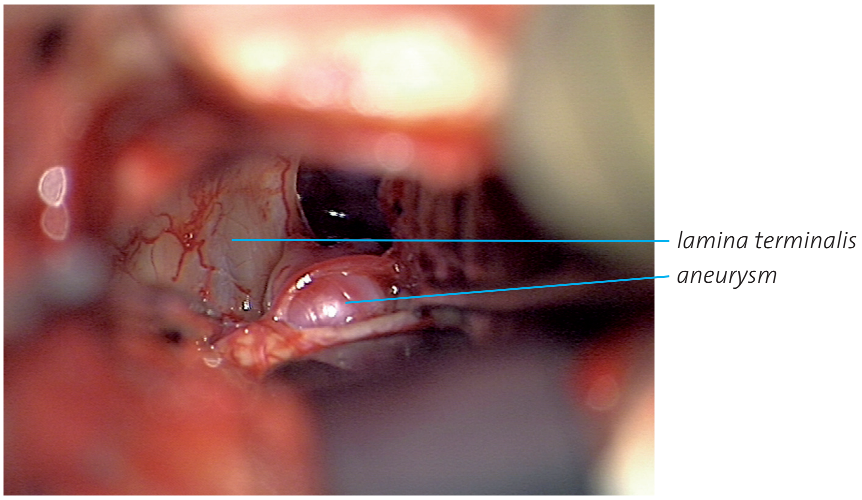


Fig. 1.0.51

Step 12

After further dissection, the entire aneurysm can be seen. Note the hypoplastic left A1 segment and the ACoA (Fig. 1.0.52).

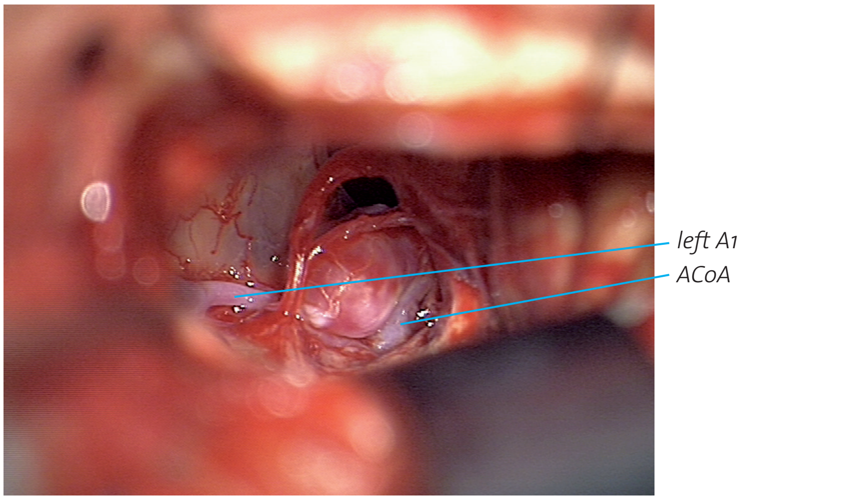


Fig. 1.0.52

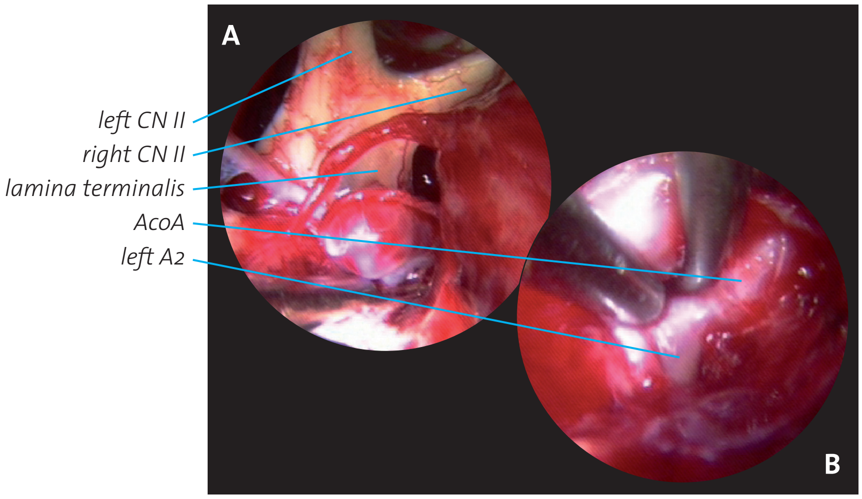


Fig. 1.0.53

Step 13

Upon introduction of the endoscope, the relationship between the aneurysm and the lamina terminalis becomes evident. Note the chiasm and both optic nerves (A). In a close-up position of the endoscope (B), the neck of the aneurysm is dissected with fine dissectors. Note the sack of the aneurysm, the left A2 and ACoA (Fig. 1.0.53).

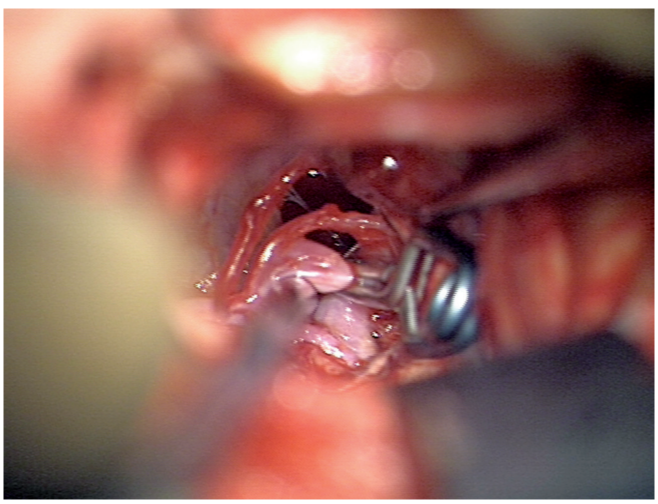


Fig. 1.0.54

Step 14

When the pathoanatomy of the aneurysm has been ascertained and the neck dissected, a straight aneurysm clip (Aesculap AG, Tuttlingen, Germany) is placed. The sack is collapsed after careful opening and aspiration of the aneurysm (Fig. 1.0.54).

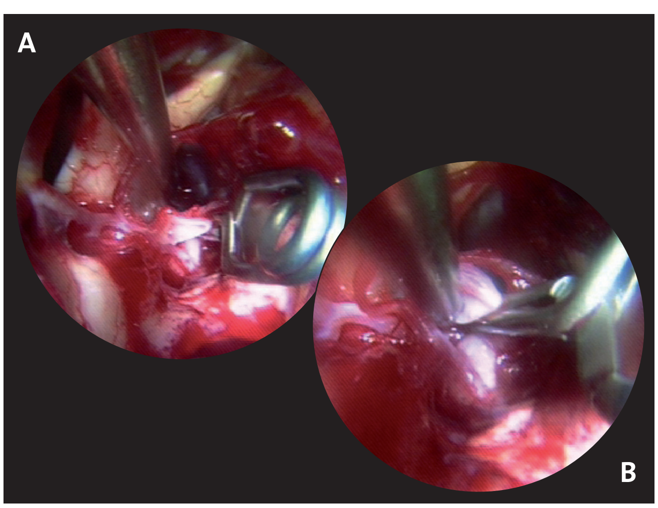


Fig. 1.0.55

Step 15

The endoscope offers adequate visual control of the clipping procedure (A). The complete closure can be effectively monitored in close-up (B) (Fig. 1.0.55).

Step 16
At the end of the intracranial procedure, the subarachnoid space is filled with artificial CSF solution at body temperature. The dural incision is closed with watertight continuous sutures. Note the extension of the limited craniotomy and minimal dural opening (Fig. 1.0.56).

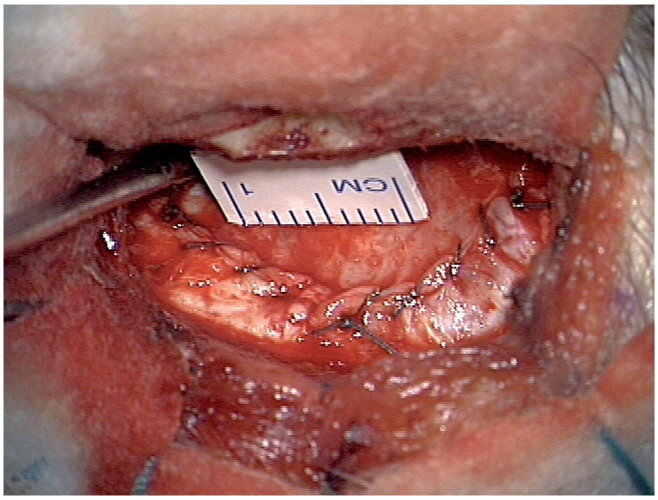


Fig. 1.0.56

Step 17
A plate of gelfoam is placed extradurally and the bone flap is fixed with a titanium Craniofix miniplate (Aesculap AG, Tuttlingen, Germany). Note that the burr hole should be closed with the plate and the bone flap tightly fixed both medially and frontally to achieve optimal cosmetic results (Fig. 1.0.57).

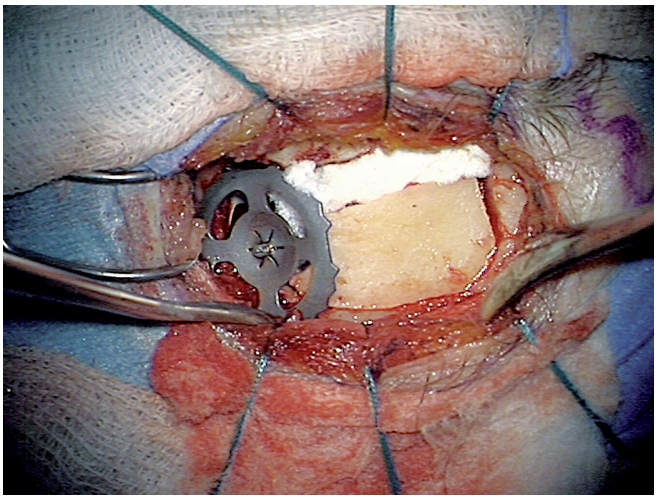


Fig. 1.0.57

Step 18
After final verification of hemostasis, the muscular and subcutaneous layers are closed with interrupted sutures and the skin with intracutaneous sutures. On account of the limited skin incision and nontraumatic surgical technique, the use of a suction drain is not necessary and therefore not recommended (Fig. 1.0.58).

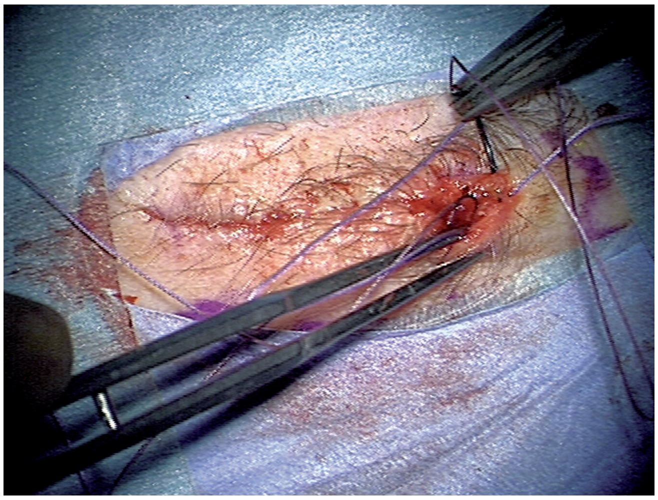


Fig. 1.0.58

Wound closure

After finishing the intracranial procedure, the subarachnoid space is filled with artificial CSF solution at body temperature. The dural incision is made watertight using either interrupted or continuous sutures (Step 16, Fig. 1.0.56). If tension has developed in the dural plane, a piece of muscle can be sewn into the dural closure. A plate of gelfoam is then placed extradurally. We do not recommend the use of fibrin or protein-containing fixative to assist with dural closure on account of the fibrinolytic effect of the CSF. The bone flap is fixed with a titanium miniplate. Usually one plate is enough to allow sufficient fixation; if possible, the titanium plate should close the burr hole trephination (Step 17, Fig. 1.0.57). Note that the bone flap should be fixed tightly to achieve optimal cosmetic results. After final verification of hemostasis, the muscle and subcutaneous layers are closed with interrupted sutures. For closure of the skin, different techniques can be used. An eyebrow skin incision can be closed with intracutaneous running sutures or with sterile adhesive tapes (Step 18, Fig. 1.0.58). A skin incision within the haired area can be closed with interrupted or running sutures or after adequate subcutaneous sutures with histoacryl glue. On account of the limited skin incision and nontraumatic surgical technique in keyhole neurosurgery, a suction drain is not required.

Fig. 1.0.59 *Patient's appearance the 2nd and 21st postoperative day. The limited skin incision, minimal muscular dissection and least possible bone damage obtained with this minimal invasive technique result in an optimal cosmetic outcome (published with patient's permission).*

Potential errors and their consequences

- Inadequate preoperative planning with subsequent inadequate exposure of the target region and significant deterioration in efficiency of surgically excising the lesion. Planning is the task of the surgeon!
- Inadequate positioning of the patient with insufficient intracranial exposure. To avoid a physiologically uncomfortable job during time-consuming procedures, the surgeon should perform the patient positioning himself.
- Inadequate placement of the craniotomy. The approach must be determined after accurate surgical orientation according to anatomical knowledge and preoperative planning. However, with the use of modern navigation tools, correct positioning of the craniotomy can effectively be monitored.
- Overlooked, but often unavoidable injury to the dura during craniotomy. Dural reconstruction may be necessary.
- Inadequate removal of CSF with injury to the cortical surface due to spatula pressure.

- Injuries to nerves and vessels in the surgical field during microsurgical manipulation resulting in postoperative neurological deterioration.
- Inadequate intracranial hemostasis causing severe postoperative rebleeding within the surgical field.
- Inadequate dural closure with postoperative CSF leak.
- Inadequate positioning and fixation of the bone flap with suboptimal cosmetic results.
- Inadequate extracranial hemostasis causing postoperative soft tissue hematoma.
- Inadequate closure of the skin causing postoperative wound healing disturbance or suboptimal cosmetic outcome.

Tips and tricks

- Take time for preoperative planning and positioning of patients. The reward is an excellent overview of the target area and an efficient working position.
- Make a careful anatomical orientation and use the three steps of marking with a sterile pen: 1. osseous structures and superficial neurovascular structures; 2. placement of craniotomy; 3. skin incision.
- The skin incision should be made in a cosmetically acceptable way.
- By retracting the soft tissue, the osseous surface should be optimally exposed. However, retraction and mobilization of the skin flap should be restricted to the necessary minimum to prevent postoperative necrosis.
- Be careful during the burr hole trephination: adequate placement but inadequate direction of the burring procedure may also penetrate structures of the skull base or may injure the dural and cortical surface!
- Stages of craniotomy: 1. burr hole trephination; 2. cutting with the craniotome according to the planned approach.
- Drilling of the inner edge of the craniotomy after removal of the bone flap is important for limited approaches to achieve unhindered intracranial visualization. Small osseous extensions of the skull base should also be carefully removed to provide an excellent overview and to allow microsurgical access to deep-seated sites.
- Open the dura in a “C” or “Y” shaped fashion and hold the dural flap with sutures.

- Many neurosurgeons believe that intracranial surgery should be done with the surgeon sitting. However, performing a keyhole approach, intraoperative changing of the surgeon's position is very frequent. In our experience, this "dancing around the table" is more comfortable for the surgeon whilst standing, even when performing long and time-consuming procedures.
- After completion of the intradural dissection, dural closure should be made watertight using either interrupted or continuous sutures. If tension has developed in the dural plane, a piece of muscle can be sewn into the dural closure.
- After dural closure, the bone flap should be tightly fixed to achieve optimal cosmetic results.
- A titanium plate can be successfully used for closure of the burr hole trephination.
- Because of the limited soft tissue dissection, the use of suction drain is not required.
- The skin should be closed within the haired area with sutures or after subcutaneous sutures with histoacryl glue.
- An eyebrow incision can be sufficiently closed with intracutaneous running sutures or with sterile adhesive tapes.