# 1 Instruments

Paolo Cappabianca, Felice Esposito, Luigi M. Cavallo
and Olga V. Corriero

## 1.1 Introduction

Among the determinants of the success of a surgical technique are an in-depth knowledge of the surgical anatomy, the combining of the expertise of the different professionals, and the availability of dedicated instruments and tools, which permit advances to take place in terms of expanding the indications, improving the results and reducing the complications.

Advances in surgical instrumentation, in hemostatic techniques and materials, and in image guidance systems, and, most importantly, collaboration between neurosurgeons and otolaryngologists/head and neck surgeons/maxillofacial surgeons, together with the contribution of new imaging devices and techniques, have resulted in recent dramatic changes in the practice of skull-base surgery, ultimately resulting in a movement toward less-invasive procedures, as in most fields of modern medicine.

If on one hand such technological advances push the development of new surgical techniques, the opposite is also true: the introduction of a novel surgical approach or technique often requires the design and refinement of new dedicated instruments and tools, contributing to the mutual relationships between surgeons and biomedical engineers and manufacturers.

Surgery of the skull base is amongst the most difficult, complex and, at the same time, rewarding experiences. Skull-base surgery does not just require the acquisition of perfect surgical skill: surgeons also need to acquire a thorough knowledge of anatomy, mastery of the pros and cons of all the materials and instruments to be used during the operation, the ability to share his/her peculiarities with others, versatility in choosing among the different approaches (transcranial, transfacial, combined transcranial–transfacial, etc.), and knowledge of the pros and cons of each one of them, etc [1, 2] .

This chapter focuses on one of these aspects: the possibilities and limitations of the main instruments and tools used during most of the surgical approaches described in the following chapters throughout the book.

## 1.2 Types of Instrument

There are two types of instrument in skull-base surgery: instruments with a single shaft and a functional tip (for example, hooks, dissectors, curettes, knives, etc), and those that fall within what the instrument manufacturers call the “forceps family” (for example bipolar forceps, tumor-holding forceps, biopsy rongeurs, vascular forceps, and scissors). Some approaches, e.g. the transsphenoidal approaches, performed under certain conditions such as endoscopy, demand dedicated instruments [11].

There are very different principles involved in handling and using these two groups of instruments. It is possible to hold the single-shaft instruments anywhere along the shaft. Where the instrument is grasped depends on the working depth, i.e. the distance between the tip of the index finger and the tissue plane being dissected. Instruments of the forceps group are very different. They are made with a definite area to grasp the

P. Cappabianca (✉)
Dept of Neurological Science, Division of Neurosurgery
Università degli Studi di Napoli Federico II, Naples, Italy

P. Cappabianca et al. (eds.), *Cranial, Craniofacial and Skull Base Surgery*.

instrument and to control the opening and closing action of the tips.

The design of microsurgical instruments should incorporate stability, flexibility, and mobility. Their use in microsurgery can be compared to that of a pencil during writing. The forearm is supported on a specifically designed rest. The hand is then free and relaxed and is supported at the surface edge of the wound by the fourth and fifth fingers. The instrument is grasped and controlled using the index and middle fingers, together with the thumb. From the opening of the dura until it has been closed by suturing, the operation is performed under the operating microscope and/or the endoscope. During this time the surgeon mainly uses the bipolar forceps and suction tip.

## 1.3 Microscope

Microsurgical techniques, which require the use of the operating microscope, are a key part of skull-base surgery and the acquisition of skill and proficiency in the use of the mobile operating microscope is the first step in microsurgery [3, 4].

The operating microscope, which as well as magnifying improves illumination and provides stereoscopic and telescopic vision, is the key instrument in the microsurgical treatment of intracranial lesions. The magnification, which is variable between ×3 and ×25, is ultimately derived from the optical relationship between the objective lens, the side of the binocular tubes, and the magnification of the eyepieces. Besides magnification, the unique characteristic of the microscope compared with the other surgical visualizing tools, such as the endoscope, is its most useful function, stereoscopic 3D vision. This function, coupled with the zoom capabilities of the optical system, brings the plane of the operative field closer to the observer, maintains the optical capacity of depth perception, and allows the surgeon to work bimanually.

The degree of illumination depends upon the light source used, on the degree of magnification (the greater the magnification, the less the passage of light), and on whether a beam splitter for the attachment of observation tubes and camera equipment is employed.

**Fig. 1.1** Modern operating microscopes are no longer just instruments to provide a magnified image, but are rather fully integrated into the modern operating room and allow information to flow between all the other instruments, offering new horizons in improving the surgical workflow

The surgeon, acting through controls on the handpieces, can rotate, raise, translate, and lower the microscope optics and make fine adjustments to its position. The other face of the medal is that the use of the microscope entails an unavoidable restriction of movement, and also requires the surgeon to maintain a restricted postural position.

Latest generation microscopes (Fig. 1.1) represent a concentration of technology and advances. They are able to combine solutions for the basic requirements—illumination and magnification of the surgical field—with a variety of additional benefits including intraoperative fluorescence, integration with endoscopy and neuronavigation devices, integration of the entire digital video chain, integration into the hospital's information and communication infrastructure, and user-friendly solutions for the operating room staff.

## 1.4 Endoscope

The endoscope permits access to deep anatomic structures in a minimally invasive manner. It allows the visualization of deep, hidden structures in the brain and transmits clear and usable images to the surgeon. Its main characteristic and advantage is that it brings the eyes of the surgeon close to the relevant anatomy. In such a way it can increase the precision of the surgical action and permit the surgeon to differentiate tissues, so that selective removal of the lesion can be achieved [5-7]. Endoscopes are classified as either fiberoptic endoscopes (fiberscopes) or rod-lens endoscopes. Endoscopes specifically designed for neuroendoscopy can be classified into four types: (1) rigid fiberscopes, (2) rigid rod-lens endoscopes, (3) flexible endoscopes, and (4) steerable fiberscopes [5, 6, 8].

These different endoscopes have different diameters, lengths, optical quality, and number and diameter of working channels, all of which vary with size. The choice between them should be made on the basis of the surgical indication and personal preference of the surgeon. In general, for endoscopic skull-base surgery, the best endoscopes are rigid rod-lens scopes (Fig. 1.2). The main advantage is the better quality of vision than with the other type. It allows the surgeon to remain oriented because of the panoramic view and permits the other instruments to be inserted alongside it. Rod-lens endoscopes consist of three main parts: a mechanical shaft, glass fiber bundles for light illumination, and optics (objective, eyepiece, relay system). The angle of view of the rod-lens ranges from 0° to 120°, according to the objective, but angled objectives of more than 30° are used only for diagnostic or visualizing purposes. The most frequently used angles are 0°, 30° and 45°. The 0° objective provides a frontal view of the surgical field and minimizes the risk of disorientation. It is used during the major part of the operation. The advantages of 30° is that this type of endoscope, through the rotation of the lens, increases the surface area of the field of view. Moreover, visualization of the instruments is improved as they converge toward the center of the image, while with the 0° objective the instruments remain in the periphery of the image.

The endoscope is usually used through a sheath, which is connected to a cleaning system. The irrigation system permits cleaning and defogging of the distal lens, thus avoiding the repeated insertion and removal of the endoscope from the nostril. Endoscopes used for endonasal skull-base surgery have no working channel (diagnostic endoscopes), and the other instruments are inserted either into the same nostril, slid alongside the sheath, or into the contralateral nostril. The diameter of rod-lens endoscopes varies between 1.9 and 10 mm, but for most surgical approaches to the skull base only endoscopes with a diameter of 4 mm are usually used. In some cases a 2.7-mm endoscope can be used. In skull-base surgery, such tools can be used freehand or fixed to a scope holder.

During the first step of the operation (the approach itself), it is better to use the endoscope freehand, so that the various instruments can be handled dynamically

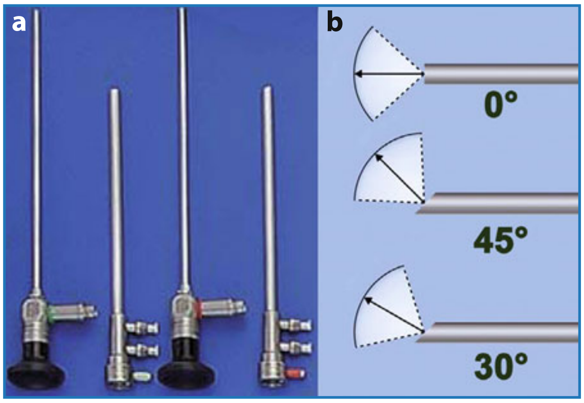


**Fig. 1.2** Rigid rod-lens endoscopes **a**, without working channels, used in skull-base surgery. They allow the surgeon to remain oriented because of the panoramic view and allow other instruments to be inserted alongside. **b** The most frequently used objective angles are 0°, 30° and 45°

while creating the working space for the later steps in the procedure. In such a way, the surgeon can progressively gain a sense of depth by fixing in mind some surgical landmarks to guide orientation. A perfect knowledge of surgical anatomy does the rest. The endoscope can then either continue to be use free-hand or be fixed to a scope holder.

For the freehand technique, the scope is used in a dynamic fashion and the surgeon continuously receives feedback about the anatomy and depth of the operative field based on the in-and-out movements of the scope. If the option of a scope holder is chosen, a variety of systems exist. Variables include a steerable or extensible arm, and a rigid or jointed arm that can be straight, curved, or pneumatic. With such devices, the endoscope is fixed in a particular position, and the surgeon can use both hands to manipulate the surgical instrumentation. Another possibility is to have the endoscope held by an assistant. With this method the dynamic movements of the scope are preserved and, at the same time, the surgeon can simultaneously use two instruments either in the same nostril or in both nostrils.

### 1.4.1 Video Camera and Monitor

The endoscope is connected to a dedicated video camera, and the endoscopic images are projected onto a monitor placed in front of the surgeon [9]. Additional monitors can be placed in other locations in the operating room, as well as in hallways or adjacent rooms, to permit other members of the team to watch the surgery. Also such tools are being continuously improved to offer high-quality endoscopic images with tremendous visualization of the operative field, and of the lesion and its relationships with the surrounding anatomical structures.

Several types of endoscopic video camera are available, the most common of which utilize a CCD (charge-coupled device) sensor. Buttons located on the camera control the focus and the zoom. Optical zoom is preferable because it enlarges the image with the same number of pixels; the electronic zoom increases the size of each pixel, which degrades the definition of the image.

The video signals are usually brought to the monitor and to the recording devices in RGB, S-video, or composite video formats. Today, digital 3-CCD endoscope cameras (with three CCD sensors) are available, which produce the highest quality images. These cameras can be directly connected to video recorders for high-quality video reproduction [10].

The images produced by the endoscope camera are displayed on one or more monitors. These monitors need to have a high-resolution screen to support the signal quality arising from the camera. The monitors most commonly used in endoscopic surgery have a minimum horizontal resolution of 750 lines, in order to visualize all the details of the endoscopic images.

A further improvement in the resolution of both the video cameras and the monitors is represented by high-definition (HD) technology (Fig. 1.3), which offers the ultimate image quality and is ready for the 3-D endoscopes of the future. A full HD 16:9 flat monitor (1080p60) needs to be coupled to the HD camera in order to visualize the HD images.

### 1.4.2 Light Source

The endoscope transmits the cold light that arises from a source (Fig. 1.4a) inside the surgical field through a connecting cable made of a bundle of glass fibers that brings the light to the endoscope, virtually without dispersion of visible light (Fig. 1.4b). Furthermore, heat is poorly transmitted by glass fibers, thus the risk of burning the tissues is reduced [7].


**Fig. 1.3** High-definition (HD) cameras **a** offer the ultimate image quality. They require a full HD 16:9 flat monitor **b** in order to visualize the HD images

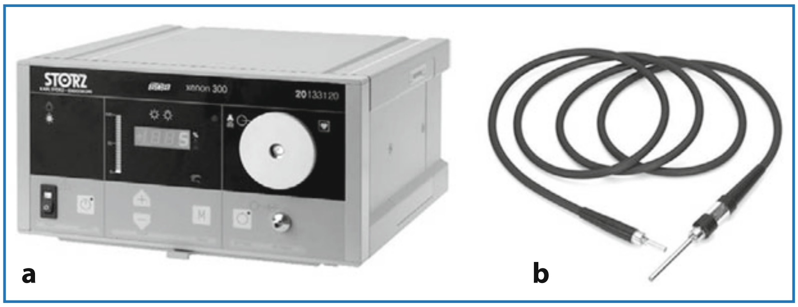


**Fig. 1.4** Xenon-based light sources **a** bring cold light to the endoscope via a cable comprising a bundle of optic fibers **b**

### *1.4.3 Video Documentation*

Several systems are available to document endoscopic surgical operations. Any one of a number of films or digital cameras, analog or digital VCRs, mass memory, CD- or DVD-based systems can store and even improve the images coming from the video camera. Such systems can be connected to dedicated devices and route the pictures and/or the videos for a complete digital exchange, for computer or video streaming or teleconferencing, for E-learning, or tele-counseling. Furthermore, it is possible for modern integrated operating rooms to share digital images and video by simply pressing a touch screen, which can even be done by the surgeon while operating.

## 1.5 Perforator and Craniotome

Craniotomy is one of the critical parts of the operation in that the surgeon is very much dependent on correct and reliable instrument function. Various perforators and craniotomes are available. Usually the different systems include a perforator (different size) craniotome, and a handpiece to attach round burrs, which are used to drill off bony structures such as the sphenoid wing, the prominence of the frontotemporal bone, the mastoid bone over the sigmoid sinuses, etc. Drilling with a burr might be performed under the operating microscope. The majority of craniotomies are made by first placing one burr hole, and then cutting the craniotomy with a craniotome. If the dura is not carefully dissected from the cranium before using the craniotome, there is a high risk that it will be torn. A selection of dissectors is necessary for adequate dural dissection. In particular, a flexible dural dissector is recommended, which is used after initially freeing the dura immediately around the burr hole with a rigid, conventional dissector. The flexible dissector is used to free the dura along the whole length of the proposed cutting line of the craniotomy.

## 1.6 High-Speed Microdrill

High-speed low-profile drills, either electric or pneumatic, may be very helpful for opening the bony structures to gain access to the dural space. A drill with forward and reverse rotation is preferred. The use of the drill should be planned so that the burr rotates away from critical structures. Only diamond burrs, and not cutting burrs, are used near important structures because only they can be used effectively in reverse. Drills for skull-base surgery should have some special characteristics. They should be low-profile and also long enough but not too bulky, so they can be easily used together with the possible combined use of the endoscope (Fig. 1.5). The combined use of such drills and

**Fig. 1.5** Low-profile extra-long drills (Anspach Effort, Palm Beach Gardens, Florida, USA), easily used in combination with the endoscope

bone rongeurs has proven to be effective and time-saving during the extended approaches to the skull base, especially for access to restricted regions. It is important to find a good balance between the length of the tip and stability during fine drilling, as a too-long tip may vibrate dangerously. The high-speed drill is used to open the internal acoustic canal, optic canal, clivus and anterior and posterior clinoids, to remove the sphenoid wing, orbit indentation and petrous bone, and to open the foramen magnum.

A specifically designed endonasal transsphenoidal handpiece has recently been introduced for the ultrasonic bone curette (Sonopet, Miwatec, Tokyo, Japan), which is very low-profile and also quite safe since it works well and precisely in removing the bone structures but, at the same time, it respects the soft tissues, thus lowering the risk of injury to the neurovascular structures that may be close to the bone structure to be removed. For example, in endonasal skull-base surgery it has proven to be useful during the removal of the tuberculum sellae in cases of a prefixed chiasm, where it removes the tumor and leaves the soft tissues, such as the dura and, obviously, the chiasm beneath.

## 1.7 Bleeding Control

One of the most difficult problems is the control of bleeding.

Monopolar coagulation is easy because it can be simply performed with the use of monopolar sticks and it is usually quite effective. For hemostasis over larger areas, special ball-tipped attachments to the monopolar cable are very efficient. They are available in a variety of sizes with straight and curved shafts. Because of the heat produced when using this method, copious irrigation following each short phase of coagulation is recommended. Some monopolar electrodes incorporate a suction cannula to aspirate the smoke during coagulation, which maintains a clear surgical field. Monopolar coagulation must be avoided close to major neurovascular structures, in the intradural space or in proximity to nerve or vascular bony protuberances within the sphenoid sinus.

Bipolar forceps are the most adaptive and functional tool available to the neurosurgeon. They not only provide bipolar coagulation, but are also the main instrument of dissection. This feature makes them particularly suitable for opening arachnoid planes, separating membranes, grasping small amounts of tumor tissue from the normal brain parenchyma, and dissecting blood vessels. The bipolar unit can be used to coagulate in areas where unipolar coagulation would be dangerous, for instance near neurovascular structures. In general, bipolar coagulation is preferable, either alone or in association with hemostatic agents. The use of the microsurgical bipolar forceps, developed for the microscope, is not feasible with the endoscope. Consequently, different endonasal bipolar forceps have been designed, with various diameters and lengths, that have proven to be quite effective in bipolar control of bleeding. New coagulating instruments, monopolar and bipolar, based on radiofrequency waves have also been proposed (Fig. 1.6). They have the advantage that the spatial heat dispersion is minimal, with a consequent minimal risk of heating injury to the neurovascular structures. Besides, the radiofrequency bipolar forceps do not need to be used with irrigation or to be cleaned every time.

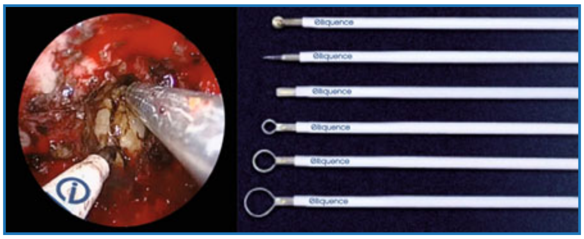

**Fig. 1.6** Radiofrequency coagulating systems (Elliquence, Oceanside, NY, USA) have the advantage of minimal spatial heat dispersion, with a consequent minimal risk of heating injury to the neurovascular structures. They can also be used to debulk fibrous lesions

## 1.8 Retraction Devices

Ideally, a brain retraction system should not compress the brain at all, but protect it. The injurious effects of retraction are directly related to the force of protective retraction and how long it is applied [12, 13]. Currently, the primary functions of retraction systems are to protect the brain, to provide gentle retraction during the initial stages of dissection, and to counteract gravity during the course of a tumor resection where the overlying cortex is tending to fall into the cavity. Today, most surgeons try to avoid the use of a retractor as much as possible and work with two instruments, mainly the suction tube which provides gentle traction after adequate room has been obtained by CSF outflow or tumor debulking.

## 1.9 MicroDoppler Probe

Prior to opening the dura mater and whenever the surgeon thinks it is appropriate (especially while working very close to vascular structures), it is of utmost importance to use the microDoppler probe to insonate the major arteries [14]. The use of such a device is recommended every time a sharp dissection is performed to minimize the risk of injury to either the carotid or the basilar artery or the other vascular structures that may be close to or even compressed by the lesion.

## 1.10 Neuronavigation System

Orientation is one of the most important factors in neurological surgery. Without proper orientation, the surgeon will waste time and sometimes do unnecessary harm to the brain. The rapid development of computer-assisted diagnostic imaging including CT, MRI , and angiography, has led to a great improvement in the diagnostic ability of neurosurgeons. These image data provide a neurosurgeon with accurate coordinates and size of a lesion and even a functional area mapping of individual cases. Some systems (image guided surgery systems or neuronavigators) correlate these data directly into the operating field.

The neuronavigator consists of a personal computer, a multijoint sensing arm and an image scanner. The three-dimensional coordinates of the arm tip are always monitored by the computer and are automatically translated into CT/MRI coordinates and finally displayed as a cursor on the CT/MRI images on the computer screen. The basic function of the navigator is to obtain the location of the arm tip within a surgical field and to translate it into CT/MRI coordinates. The patient's head should initially be related to the CT/MRI coordinates. The relationship is established using a set of fiducial points on the patient's head.

Intraoperatively, the location of the navigator tip is thereafter automatically converted into the CT/MRI coordinates and projected onto the corresponding CT/MRI slice on the computer screen represented by cross-shaped cursors. The system thus provides information on the location of the instruments in terms of the CT/MRI coordinates which guides the surgeon during the operation.

Neuronavigation systems also make it possible to avoid the use of fluoroscopy, thus avoiding unnecessary radiation exposure to the patient and the surgical team.

## 1.11 Intraoperative MRI

Despite many technical and instrumental advances, the extent of resection is often difficult to assess and is sometimes largely overestimated by the surgeon. This was demonstrated after introducing intraoperative MRI (iMRI) into the operating room. The implementation of iMRI in standard neurosurgical procedures has been widely appreciated due to the benefit of immediate tumor resection control. Besides the advantage of approaching a tumor without x-ray exposure of the patient and staff, the use of an iMRI integrated navigation system allows precise intraoperative tracking of residual tumor based on updated images acquired within minutes while surgery is paused. Thus remaining tumor can be removed by further navigation-guided resection. Intraoperative MRI systems differ with respect to scanner features (low field [15–18] or high field [19]) and their impact on the ergonomic workflow, which means either patient or scanner movement. Recently the first papers reporting the use of a 3-T iMRI [20, 21] have been published.

## 1.12 Tumor Enucleation

The best instrument for tumor enucleation is the suction apparatus. For slightly firmer tumors that are more resistant, the best technique is to grasp a portion of the tumor with ring-tipped forceps or a fork, or even a biopsy rongeur, and to apply gentle traction, while using dissectors in one hand to help free and finally lift away a portion of tumor. A selection of biopsy rongeurs in two different lengths (long and short) and with a variety of jaw sizes, is available. A large, rigid tumor can be excised with scissors, with the bipolar or monopolar loop attachment.

The loop for the monopolar electrode is available in a variety of sizes and permits rapid debulking of firm tumors. Furthermore, radiofrequency monopolar ball electrode technology (Elliquence, Oceanside, NY, USA), which uses radiofrequency power to vaporize the tumor thus obtaining an effect similar to that achieved with an ultrasonic aspirator system, is particularly useful for central debulking of a meningioma, particularly if it is of firm consistency, before starting the dissection of its capsule from the surrounding neurovascular structures (Fig. 1.6).

For the debulking of softly to moderately firm tumor, ultrasonic aspirator systems have proven to be helpful

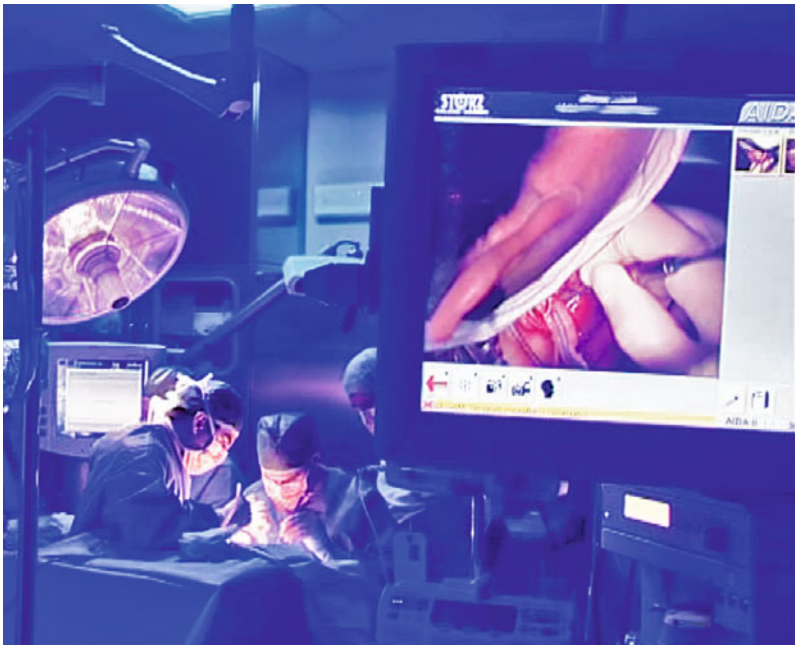

**Fig. 1.7** Modern integrated operating room helps optimize teamwork and all the equipment is controlled via user-friendly interfaces

in open cranial surgery. The system relies on a titanium shaft that moves axially at ultrasonic speeds to emulsify tissue 1–2 mm from the tip. It supplies continuous irrigation and suction to aspirate the emulsified tissue.

## 1.13 Operating Room

The design of the operating room can itself be considered a surgical instrument. An integrated operating room helps to optimize teamwork and improve patient care [5, 22]. In the modern operating room, all the equipment is controlled via a user-friendly interface that provides a great sense of personal accomplishment among surgeons, anesthesiologists and nurses (Fig. 1.7).

The main characteristics of such a modern operating room are:

- Compartmentalization of sterile and nonsterile activities
- Fluidity of the workflow during the procedure
- Optimal access to the patient in case of emergency.

Thanks to communication technology the operating room may become a world surgical amphitheater: internet allows real-time, two-way transmission of digital encrypted data throughout the world.

During surgical procedures the archiving system is an efficient and cheap mechanism for storing and analyzing neurosurgical images. All patient data collected during surgery are transmitted and stored for future reference; they are easily accessible, confidential and protected from manipulation. These technological advances provide the best possible care to patients, ultimate ease and convenience to the surgical team, and excellent quality education and training to students, residents and visiting surgeons.

## References


1. Cappabianca P (2006) Advice for a young neurosurgeon. Surg Neurol 65:35–37
2. Cappabianca P, Decq P, Schroeder HW (2007) Future of endoscopy in neurosurgery. Surg Neurol 67:496–498
3. Yasargil MG (1996) Instrumentation and equipment. In: Yasargil MG (ed) Microneurosurgery. Thieme, Stuttgart New York, pp 2–25
4. Yasargil MG (1996) Laboratory training. In: Yasargil MG (ed) Microneurosurgery. Thieme, Stuttgart New York, pp 26–27
5. Cappabianca P, Cavallo L, de Divitiis E (2008) Endoscopic pituitary and skull base surgery. Anatomy and surgery of the endoscopic endonasal approach. EndoPress, Tuttlingen
6. Cinalli G, Cappabianca P, de Falco R et al (2005) Current state and future development of intracranial neuroendoscopic surgery. Expert Rev Med Devices 2:351–373

7. Leonhard M, Cappabianca P, de Divitiis E (2003) The endoscope, endoscopic equipment and instrumentation. In: de Divitiis E, Cappabianca P (eds) Endoscopic endonasal transsphenoidal surgery. Springer, Vienna New York, pp 9–19
8. Cappabianca P, Cinalli G, Gangemi M et al (2008) Application of neuroendoscopy to intraventricular lesions. Neurosurgery 62 [Suppl 2]:575–597
9. Tasman AJ, Stammberger H (1998) Video-endoscope versus endoscope for paranasal sinus surgery: influence on stereoacuity. Am J Rhinol 12:389–392
10. Tasman AJ, Feldhusen F, Kolling GH, Hosemann W (1999) Video-endoscope versus endoscope for paranasal sinus surgery: influence on visual acuity and color discrimination. Am J Rhinol 13:7–10
11. Cappabianca P, Alfieri A, Thermes S et al (1999) Instruments for endoscopic endonasal transsphenoidal surgery. Neurosurgery 45:392–395; discussion 395–396
12. Wise BL (1994) A review of brain retraction and recommendations for minimizing intraoperative brain injury. Neurosurgery 35:172–173
13. Zhong J, Dujovny M, Perlin AR et al (2003) Brain retraction injury. Neurol Res 25:831–838
14. Dusick JR, Esposito F, Malkasian D, Kelly DF (2007) Avoidance of carotid artery injuries in transsphenoidal surgery with the Doppler probe and micro-hook blades. Neurosurgery 60:322–328; discussion 328–329
15. Black PM, Moriarty T, Alexander E 3rd et al (1997) Development and implementation of intraoperative magnetic resonance imaging and its neurosurgical applications. Neurosurgery 41:831–842; discussion 842–835
16. De Witte O, Makiese O, Wikler D et al (2005) Transsphenoidal approach with low field MRI for pituitary adenoma (in French). Neurochirurgie 51:577–583
17. Hadani M, Spiegelman R, Feldman Z et al (2001) Novel, compact, intraoperative magnetic resonance imaging-guided system for conventional neurosurgical operating rooms. Neurosurgery 48:799–807; discussion 807–799
18. Steinmeier R, Fahlbusch R, Ganslandt O et al (1998) Intraoperative magnetic resonance imaging with the magnetom open scanner: concepts, neurosurgical indications, and procedures: a preliminary report. Neurosurgery 43:739–747; discussion 747–738
19. Fahlbusch R, Keller B, Ganslandt O et al (2005) Transsphenoidal surgery in acromegaly investigated by intraoperative high-field magnetic resonance imaging. Eur J Endocrinol 153:239–248
20. Hall WA, Galicich W, Bergman T, Truwit CL (2006) 3-Tesla intraoperative MR imaging for neurosurgery. J Neurooncol 77:297–303
21. Pamir MN, Peker S, Ozek MM, Dincer A (2006) Intraoperative MR imaging: preliminary results with 3 tesla MR system. Acta Neurochir Suppl 98:97–100
22. Cappabianca P, Cavallo LM, Esposito F et al (2008) Extended endoscopic endonasal approach to the midline skull base: the evolving role of transsphenoidal surgery. Adv Tech Stand Neurosurg 33:151–199