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Basic principles and equipment in neuroendoscopy

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A fool with a tool is... still a fool. Lars Leksell

The advent of neuroendoscopy has had a remarkable impact on the field of neurosurgery. Although the use of an endoscope to diagnose and treat various central nervous system (CNS) conditions, particularly those confined to the ventricular system, has been well recognized for years [1–7], the story of modern neuroendoscopy is just beginning. It has been attended by a number of remarkable breakthroughs in optical physics, technology, and instrumentation. Needless to say, understanding the basic physics and instrumentation underlying today's endoscopes is essential for safe and successful work with these delicate instruments. This article presents a basic overview of the technology that literally brought light into the depths of contemporary neurosurgery.

Today's market is saturated with neurosurgical endoscopes, with many companies producing similar pieces of equipment. Any article attempting to comprehensively list the advantages and disadvantages of each endoscope on the market today will probably be somewhat outdated by publication because of the rapid progress in this field. This article therefore does not even attempt to provide a full list of all commercially available endoscopes with their descriptions. The authors simply intend to provide readers with a general overview of the selected endoscopes, including a brief explanation of their respective advantages and disadvantages.

A brief history of optics

Roots of the modern rigid endoscope

Until the sixties, the optic chains in a lens system were constructed of small glass lenses interspersed with large air spaces. A British physicist named Hopkins realized that the total amount of light transmitted through an endoscope is proportional to the refraction index of the material used and that using more glass than air would increase the amount of light by a factor of about 2. He restructured the lens system to consist of long glass lenses interspersed with small lens-like air spaces [3]. These "rigid rod lens scopes," with their increased light transmission ability, form the basis of most modern endoscopic systems (Fig. 1).

Further reduction in light loss is achieved through a special coating of the glass surfaces to minimize light reflection. Uncoated glass surfaces usually lose about 5% of their light through reflection. Because endoscopes consist of multiple glass lenses, the cumulative light loss can become significant. The solution is to coat the glass surface with an ultrathin layer of magnesium fluoride. This layer markedly decreases the reflection and improves the optic characteristics of endoscopes and cameras [3,8,9].

Understanding fiberoptics

Before the sixties, endoscopists used miniature tungsten light bulbs inside the endoscopes. These bulbs had two disadvantages, however: the heat generated by the bulbs could easily burn tissues, and the bulbs could not emit blue light waves, so a red color would dominate the working field. Fortunately, fiberoptic cables were invented in the

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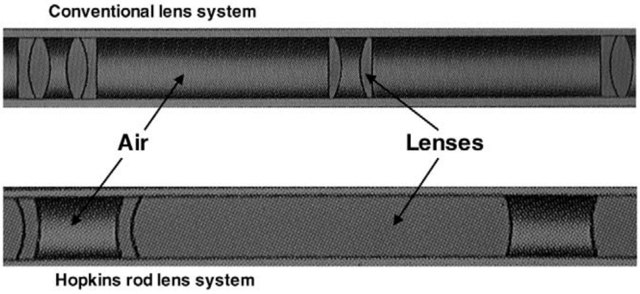

Fig 1. Conventional and rod lens systems.

sixties, a major breakthrough for endoscopic technology. With their development, the light source could be separated from the endoscope and its emitted lighted transmitted via fiberoptic cables to the tip of the endoscope. This avoided the problem of tissue injury from heat and also delivered a more natural light. Specialized cables could also be used to conduct images to a camera. Fiberoptic cables are made of individually coated flexible fibers with an inner core of silica glass. Fiberoptic bundles can be arranged in two ways [3]:

- Coherently—the proximal end portrays the image exactly as it is perceived distally. A coherent arrangement is used for visualization during surgery.
- Incoherently—fiber bundles transmit light only. An incoherent arrangement is used to transmit light to the surgical site.

Most modern fiberoptic endoscopes contain a minimum of 10,000 coherent fibers. Some contain as many as 30,000 fibers. A greater number of fibers is an advantage, because the resolution of fiberoptic endoscopes is proportional to the number of fibers in the endoscope. More fibers provide an image with a much sharper resolution.

Although a great number of fibers in bundles used to transmit images is an obvious advantage, it is not so gainful when it comes to transmission of light from the source box to the scope tip. Having many individual fibers bundled together in light source cables increases the total surface area and leads to a loss of 30% to 40% of the light being transmitted through all those individual fibers. Thus, contrary to popular belief, the light that emerges from the proximal tip is somewhat weaker than the light that enters the endoscope at the original source [3]. Light loss is discussed in greater detail later in this article in the section on light sources.

Working with optic angles

The tip of the scope can be bent to different angles, bringing different aspects of the surgical field into view. These angles are obviously fixed in the rigid solid lens scopes as opposed to the flexible fiberoptic scopes, where the tip can be manually deflected to change the angle of view off the scope's long axis. For the rigid solid lens scopes, the most commonly used angles are: 0°("head-on"), 30°, 70°, and 120°. The 0° deflection scopes portray only what they are viewing head-on, minimizing the risk of disorientation. The angled scopes are more versatile in that they visualize areas that would otherwise be out of view or difficult to illuminate. The major disadvantage of angled scopes is that the indirect image may cause the surgeon to become disoriented. The authors encountered orientation difficulties mostly when operating on patients with congenital lesions, such as arachnoid and porencephalic cysts. Similar problems may also be encountered in endoscopically assisted transsphenoidal surgery and intracranial tumor removal. Steerability of fiberoptic endoscopes adds another element to the problem of disorientation. Extensive experience is necessary to get used to oblique and "around-the-corner" views.

Light sources

An endoscope's light source is extremely important, often becoming a limiting or facilitating factor. Currently, most neurosurgeons use high-intensity xenon light sources. The light is transmitted through incoherent fiber bundles to the surgical field. Setting the light source to between 300 and 500 W provides a superior picture quality. Other types of light sources, such as halogen, are not used in modern endoscopy because they do not generate a bright enough light.

Light loss in a fiberoptic system is a significant issue. As a rule, 30% of light is lost at the lamp, because up to 30% of the surface area consists of cladding and filler, which absorb and reflect light. Fiber mismatch (between the incoherent cable bundles and the coherent optic fiber bundles) accounts for another 20% loss. Significant loss also occurs because of mismatch between the wider transmitting cable and the thinner scopes used in neurosurgery. Additional light is also lost from inadvertent reflection in various surfaces. Thus, at best, only about 30% of the light generated within the light source reaches the distal tip of the scope [3,8]. This problem is still awaiting a technologic solution.

Cameras

The chip camera, or charged-coupled device (CCD), is a critically important part of any endoscopic system. Invention of the chip camera was a remarkable technologic achievement, allowing a significant decrease in the size of the endoscope combined with an improvement in the quality of the transmitted image in comparison with previously used tube cameras. Two kinds of CCDs are currently used in neuroendoscopy: the single-chip camera and the three-chip camera.

The principle used in chip camera technology is the same as in the microprocessor industry. The chips consist of horizontal and vertical photosensitive elements that are arranged in intersecting lines. The points of intersection correspond to pixels, or picture units, that appear on the display screen. Light reflected by the object being viewed hits each pixel, and a current is generated. Each pixel on the display appears either brighter or dimmer depending on the voltage of the current signal sent to that pixel. The voltage is a function of the brightness of the image being portrayed: a brighter point on the original object being viewed generates a higher voltage current, triggering a brighter image on the display screen. The exact current voltage sent to each point is not just an approximation or estimate; it is actually a precise numeric representation of the energy generated when light hits the horizontal and vertical matrix of the camera. A digital image incorporating a complete set of picture units (pixels) is stored in the camera's memory [8].

Most endoscopic systems now use single-chip cameras. A good resolution for neuroendoscopy is available with 0.5-in cameras. When the resolution of the one-chip camera is not enough, the image may be computer enhanced.

Three-chip cameras provide better picture quality. The authors use the David-3-Chip-Camera from Aesculap (Center Valley, Pennsylvania), which features a resolution of more than 800 horizontal lines, compared with 500 lines in the standard 0.5-in micro-lens-on-chip technology camera (Fig. 2). The improved image of the three-chip camera comes at a price, however—a somewhat larger camera size and higher cost.

Video monitors

The monitor is an integral part of every endoscopic system (Fig. 3). Three things should be considered in selecting a monitor: resolution, screen size, and cost.

A higher resolution monitor provides better picture quality. There is no advantage to a monitor resolution that is significantly better than the camera resolution, however, because the monitor only displays the image seen and processed by the camera. The monitor cannot improve the camera's image. By the same token, a top-quality image from the highest resolution camera must still be displayed on the monitor, so a lower resolution monitor ruins even the best camera image.

When choosing the screen size, remember that the camera output is displayed over an area significantly larger than the cross section of the optic cable. As an image is enlarged, the image resolution and quality decrease. Screens larger than 13 in display poorer quality images because of reduced resolution. This becomes even a greater problem with images generated with a fiberoptic scope. The pixels that are only slightly visible

Fig 2. 3-chip CCD camera (Aesculap, Center Valley, Pennsylvania).

Fig 3. 100Hz monitor (Sony, New York, New York) and 3-chip CCD camera (Aesculap, Center Valley, Pennsylvania).

when fiber scopes with reasonable resolution are transmitted to a screen smaller than 13 in undergo magnification with consequent enlargement of pixels when projected to larger screens. Conversely, larger screens are useful for displaying multiple images. Finally, note that it is often most cost-effective to purchase a monitor from the manufacturer that supplies the rest of the system.

Endoscopic components and tools

Peel-away catheter

Because the concept of minimally invasive surgery lies at the heart of neuroendoscopy, every stage of the procedure, from cannulation of the fluid space to exit, should minimize interference with the patient's anatomic structures. During an endoscopic procedure, the surgeon may need to insert and remove the scope many times. It is therefore logical to create a single "safe passageway" that allows multiple reinsertions of the scope along the same tract without jeopardizing surrounding brain.

Most surgeons today use disposable peel-away catheter introducers (eg, those manufactured by Cook [Cook Critical Care, Bloomington, IN] or Neuroview [Integra NeuroSciences, Plainsboro, NJ]). These may be attached to the scalp or drapes with Steri-strips (3M Health Care, St. Paul, MN) or staples. Both tapered and blunt-tip catheters are available (Fig. 4). The catheter is supplied in various diameters ranging from number 3 to number 49 French. The most popular sizes in neuroendoscopy fall between number 10 and number 20 French. Number 10 French catheters are appropriate for 2- to 4-mm diameter endoscopes, whereas number 20 French catheters are good for the larger 6- to 8-mm endoscopes. Larger diameter introducers are not used in neuroendoscopy.

Fig 4. 15F "peel-away" blunt and tapered tip introducers.

The disadvantage of using a peel-away introducer is that it can cause bleeding because of injury to the choroid plexus or intraventricular veins on insertion. Unfortunately, only Neurocare's (Integra NeuroSciences, Plainsboro, NJ) number 9 French catheter has centimeter markings. Therefore, the authors have found it helpful to apply some bone wax 5 cm from the tip of the introducer to prevent unnecessarily deep insertion of the catheter and damage to intraventricular structures.

Alternatively, one can use an obturator/operating sheath. This is a reusable metal pipe that can only be attached with a scope holder, which can be a slight inconvenience. The introducers and the sheath enable multiple reinsertions of an endoscope without repeated recannulations.

Rigid endoscopes

Most neurosurgeons today still use rigid glass endoscopes that are neither flexible nor steerable. An advantage of rigid rod lens scopes is that smaller diameter lenses may be used, allowing the endoscope designer to either decrease the diameter of the whole scope, producing a smaller and more delicate instrument that can reach more inaccessible areas, or add more space to the working channel, producing an instrument that can accomplish many tasks for the surgeon. The basic rigid glass endoscope consists of three elements: an optic system, a working channel, and an irrigation port (Fig. 5). Table 1 summarizes the features of the most common rigid endoscopes. The remainder of this section discusses the advantages and disadvantages of typical endoscopes available from various manufacturers.

- The Gaab Neuro-Endoscope (K. Storz, Tuttlingen, Germany) has a 6.5-mm operating sheath, with a 3-mm working channel. Fiberoptic light transmission is incorporated. The Gaab endoscope with a 2-mm operative Hopkins telescope is a popular choice for surgery because it allows visualization during surgical instrumentation with specially designed rigid instruments. The 4-mm 0°, 30°, 70°, and 120° diagnostic scopes are popular for diagnostic orientation in the ventricular system, basal cisterns, arachnoid cysts, or cystic tumors. Because these diagnostic scopes do not have a working channel, they have room for larger diameter lenses and are therefore able to provide exceptionally clear visualization and orientation. Note that Codman & Shurtleff (Johnson & Johnson, New Brunswick, NJ) also manufactures the Gaab Neuro-Endoscope. The outer diameter of the Codman & Shurtleff endoscope is only 5.8 mm, however, and the diameter of the working channel is 1.6 mm.
- The Chavantes–Zamorano Neuro-Endoscope (K. Storz) has a relatively large outer diameter of 8 mm. It has one central 3-mm working channel and two separate suction and irrigation channels, which can also be used for flexible instruments. Better visualization can be achieved with the smaller diameter 30° and 70° diagnostic scopes. This endoscope also has a manometer for constant monitoring of intracranial pressure during surgery. The disadvantage of the Chavantes-Zamorano system is that the scope has a relatively large diameter and the overall size impedes maneuverability. Nevertheless, many neurosurgeons use this endoscope, especially for evacuation of intracerebral and, particularly, intraventricular hematomas, in conjunction with stereotaxy. Note that Codman & Shurtleff also manufactures the Chavantes-Zamorano endoscope. The difference is that the diameter of that endoscope's working channel is 1.9 mm.
- The Auer Neuro-Endoscope (K. Storz) has an outer diameter of 6.6 mm. This endoscope features two working channels: a straightforward 0° telescope that is 2.9 mm in diameter and an adapter for a Greenberg retractor. The larger size of the Auer endoscope is a major disadvantage; however, the excellent optics and specially positioned irrigation and suction apertures at the tip of the endoscope facilitate a clear view of the field.
- The Decq Neuro-Endoscope (K. Storz) comes in two models. The 3.5-mm × 5.2-mm model is suitable for rigid or flexible instruments of 1.7 mm in diameter. The 4.0-mm × 7.0-mm model is suitable for instruments of up to 3 mm in diameter. The telescope uses the Hopkins lens system with a 30° angle of vision.
- Aesculap produces an endoscope with a 6.2-mm operating cannula (Fig. 6). This model includes a 2.2-mm working channel, one diagnostic endoscope channel, one irrigation channel, and one overflow channel. This endoscope is available in two lengths: 250 mm, which is compatible with stereotactic frames, and 160 mm. The major advantage of this scope is excellent image quality; however, the large size is a limiting factor.

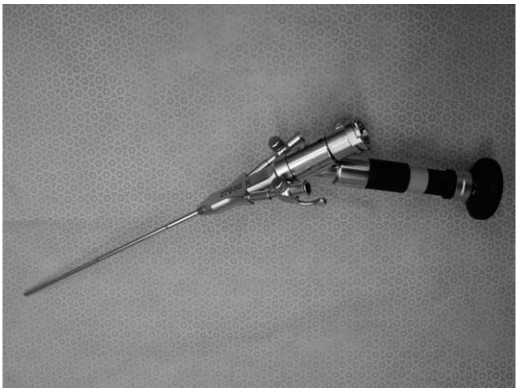

Fig 5. 3.2 mm rigid endoscope (K. Storz, Tuttlingen, Germany).

Table 1
Basic features of rigid endoscopes

Endoscope	Outer diameter	Channels	Diameter of working channels	Angles of diagnostic scopes	Remark/clinical use
Neuroview 700R (NeuroNavigational)	5.6 mm	1 working	2.0 mm	0°, 30°, 70°	Glass rod optics, Good image, Quite thick and heavy
		1 irrigation			
		1 overflow			
		1 scope	2.8 mm		
Aesculap	6.2 mm	1 working	2.2 mm	0°, 30°	Glass rod optics, Good image, Quite thick and heavy, Good for stereotaxy
		1 irrigation			
		1 overflow			
		1 scope	2.7 mm		
MINOP (Aesculap)	3.2 mm	1 working/scope	2.8 mm	0°, 30°	Glass rod optics, Good image, Short, maneuverable
	4.6 mm	1 working/scope	2.8 mm		
		1 irrigation			
		1 overflow			
	6.0	1 working	2.2 mm		
		1 irrigation			
		1 overflow			
		1 scope	2.8 mm		
Gaab endoscope (Storz/Codman & Shurtleff)	6.5 mm (5.8 mm)	1 working	3.0 mm (4.0 mm)	0°, 30°, 70°, 120°	Glass rod optics, Good image, Quite thick and heavy
		1 irrigation			
		1 overflow			
		1 scope			
Chavantes-Zamorano (Storz/Codman)	8.0 mm	1 working/scope	3.0 mm (1.9 mm)	0°, 30°, 70°	Glass rod optics, Good image, Quite thick and heavy, Features manometer for ice intracranial measurement, Good for evacuation of hematomas
		1 irrigation			
		1 overflow			
Auer endoscope (Storz)	6.6 mm	2 working		0°	Glass rod optics, Good image, Quite thick and heavy, Adapter for Greenberg retractor
		1 irrigation			
		1 overflow			
		1 scope	3.0 mm		
Decq endoscope (Storz)	Oval 3.5 × 5.2 mm	1/2 working	1.7 mm	30°	Glass rod optics, Good image
		1 irrigation			
		1 overflow			
		1 scope	3.0		
	Oval 4.0 × 7.0 mm	1/2 working			Glass rod optics, Good image, Quite thick and heavy
		1 irrigation			
		1 overflow			
		1 scope			

- The MINOP Neuroendoscopy System (Aesculap) includes the following (Fig. 7):
  - Trocars with three different shaft diameter options. The 3.2-mm model has one optic/working channel. The 4.6-mm model has three optic/working, irrigation, and overflow channels. The 6.0-mm model has four optic/working, additional working, irrigation, and outflow channels.
  - 2.7-mm endoscopes that are angled to 0° and 30°. These are suitable for freehand surgery as well as for fixation by the scope holder.

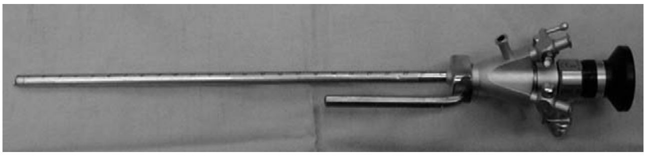

Fig 6. 6.2 mm rigid endoscope (Aesculap, Center Valley, Pennsylvania).

  - Rigid instruments and electrodes
  - Good image quality; they are suitable for "pure" ventriculostomy, endoscopic surgery, or endoscope-assisted microsurgery:
- Rigid wide-angled endoscopes for endoscope-assisted cranial neurosurgery; 0°, 30°, and 70° angles of view are also available from Aesculap.
- The "classic" model Neuroview rigid scope, produced by NeuroNavigational (Integra NeuroSciences, Plainsboro, NJ), offers superior imaging characteristics. The outer diameter of the scope is 5.6 mm, with a 2.0-mm working channel, irrigation and aspiration ports, and a 2.8-mm scope channel. The scopes are 2.7 mm in diameter and are available with 0°, 30°, and 70° offset angles, providing 80° of view.

Despite higher image quality, the classic design multiple-use scopes have some disadvantages. First, because the camera is directly attached to the scope, they are quite heavy and cumbersome. Second, the classic scopes are thicker, leaving larger holes in the brain. Third, there is a significant risk of cross-contamination. Many surgeons, unfortunately, are familiar with bouts of postoperative infections secondary to cross-contamination occurring during endoscopic procedures. Finally, because of natural wear and tear of the optical components, the image quality deteriorates after prolonged use. It was thus inevitable that disposable endoscopes would be introduced into practice. Note, however, that disposable rigid endoscopes do not use a rigid lens optic system, because rigid lenses require a larger diameter. Instead, a 10,000- to 30,000-pixel fiberoptic system is used. The quality of an image obtained through multipixel fiberoptic bundles is still significantly lower than that obtained with rigid lenses. Conversely, with disposable scopes, the surgeon receives a brand new set of optical components each time, which eliminates the problem of wear and tear.

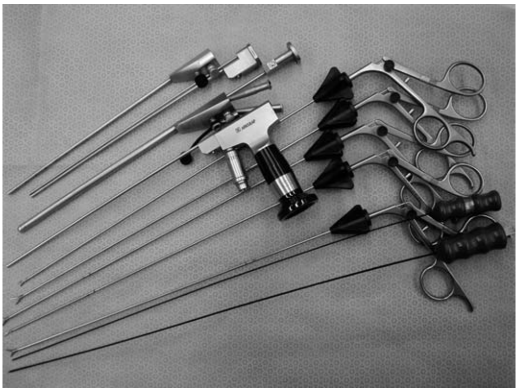

Fig 7. 4.6 mm rigid endoscope (Minop, Aesculap, Center Valley, Pennsylvania).

Fiberoptic endoscopes

This section discusses the flexible and rigid fiberoptic neuroendoscopes produced by a few different companies. Table 2 compares the advantages and disadvantages of rigid versus flexible endoscopes.

Several types of flexible scopes are available from Aesculap:

- A steerable scope with an outer diameter of 3.9 mm. This scope has a 1.1-mm working channel and a 0.5-mm suction channel. Unidirectional steerability allows 160° turns.
- A steerable scope with an outer diameter of 2.9 mm. This scope does not have a working channel. Although this scope is mainly used for inspection purposes, a steerability of 140° up and down makes this a reasonable choice for dissection.
- A series of nonsteerable flexible endoscopes with outer diameters ranging from 0.7 to 2.3 mm. None of them, except the 2.3-mm scope (see section on syringomyeloscope), have working channels. This group of endoscopes is usually used for endoscopic inspection, endoscopy-assisted surgery, or passing through a shunt. These nonsteerable endoscopes are superior to disposable flexible scopes in image quality because they use higher pixel optical fibers.

Table 2
Comparison of rigid and flexible scopes

	Rigid scopes	Flexible scopes
Advantage's	Better image Higher resolution Wider view Better color Better light transmission Light weight of disposable scopes	Steerability Application in spine *For some light weight, because camera not attached to scope*
Disadvantages	Less maneuverable Not applicable in spine	Poor image Pixel granules Narrower view Less true color Worse light Smaller working channel Limited selection of scopes and instruments

- Aesculap produces another endoscope originally designed by Perneczky. This instrument is able to "look around the corner" while operating with the microscope. The Perneczky endoscope consists of a fiberoptic scope encased in a rigid shaft with an 80° curved tip 1.4 mm in diameter. Using this curved tip, structures in the operating field that are hidden from direct microscopic view can be inspected. The Perneczky endoscope may be set into a desired position with a scope holder (see section on scope holders).

Two types of flexible scopes are available from Codman & Shurtleff:

- Codman & Shurtleff produces a steerable neuroendoscope that is similar to the 3.9-mm endoscope from Aesculap. Its outer diameter is 4 mm, with a 1-mm working channel that accepts several types of instruments and accessories. The distal viewing tip can be rotated 100° to 160° via a thumb control unit.
- Codman & Shurtleff also produces the Epic microvision. The Epic microvision is a semiflexible endoscope 1.8 mm in diameter with a bayonet-like design. The angle of the scope can be changed by inserting it into more rigid cannulas with straight, 20°, or 45° angles. Such small scopes can be used for:
  - Better intraoperative visualization, particularly in conjunction with an operative microscope, when an "around-the-corner" view is required
  - Blunt perforation of membranes when the scopes themselves are used as dissecting and fenestrating tools
  - Endoscope-assisted shunt placement when they are easily passed through the ventricular catheter as described in the following section.

Other fiberoptic scopes options include:

- NeuroNavigational produces a few disposable flexible endoscopes with outer diameters of 1.2, 2.3, and 4.6 mm. These scopes feature a rigid design with 10,000 pixel optical fibers for fine image resolution. The camera is elongated and not directly connected to the endoscope body, which significantly decreases the weight of the instrument and makes its pencil-like body easy to handle. The 0.9-mm Neuroview Fiberscope is one of the thinnest endoscopes available today. The 1.2-mm scope has only irrigation channels and is designed to fit into the lumen of shunt catheters. The 1.5-mm scope has a 0.49-mm working channel, and the 2.3-mm scope has a 1-mm working channel and a deflected tip, which improves maneuverability and access in confined areas. The 4.6-mm scope has two working channels.
- A few lightweight endoscopes are offered by Clarus (Minneapolis, MN), including the rigid fiberoptic Channel endoscope. It is quite light and can be held as a pen (Fig. 8). The Channel endoscope is available in two lengths: 13.0 and 21.6 cm. The working channels may be either 3.15 or 2.15 mm in diameter. Irrigation is available through the irrigation port, with outflow through the working channel. Other fiberoptic endoscopes from Clarus include the MurphyScope and

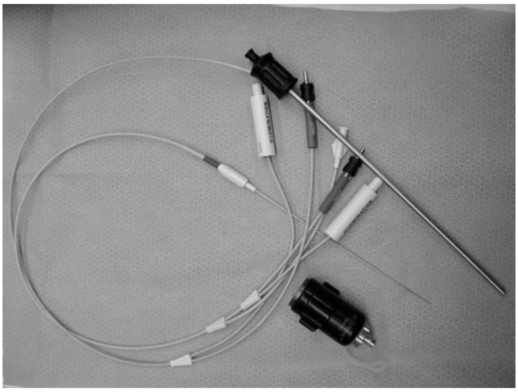

Fig 8. Light-weight fiberoptic endoscope (Clarus, Minneapolis, MN).

the NeuroPen (designed for shunt insertion). Three variants of the MurphyScope are available: 2.3-mm scopes with a bayonet-like malleable 40° angle, a straight 50° curved endoscope, and a 1.4-mm curved malleable scope.

Comparison of rigid and flexible endoscopes

Rigid and flexible endoscopes each have advantages and disadvantages. Table 2 highlights some of the pros and cons of each.

Endoscopes for shunt placement

It has been hypothesized that the use of a small-diameter endoscope as a stylet within the ventricular catheter may allow more accurate catheter positioning within the ventricle, which should decrease the number of proximal shunt malfunctions and revisions [5,10]. This theory has never been proven. Nevertheless, several types of fiberoptic endoscopes are commercially available for ventricular catheter placement. NeuroNavigational, Clarus, Cordis (Miami, FL), and Codman (Johnson & Johnson, New Brunswick, NJ) all produce semirigid lightweight scopes that have 10,000 optic fibers, providing adequate visualization of intraventricular structures. The NeuroNavigational 1.2-mm Neuroview endoscope, a disposable unit, can be used in conjunction with several ventricular catheter modifications, such as the commonly used Innervision catheter from PS Medical (Goleta, CA). The Neuroview endoscope can be used as a stylet to insert the catheter. Note that although using this technique to insert the catheter may decrease the possibility of completely missing the ventricle, it does not necessarily improve the surgical outcome once the surgeon is within the ventricle, because no specific place within the ventricle has been proven superior to any other [5].

Syringomyeloscope

Endoscopes can be used in surgical treatment of syringomyelia. Aesculap produces a flexible syringomyeloscope with an outer diameter of 2.3 mm. This scope has a working channel 1 mm in diameter, which may be suitable for 400-μm laser fibers. This endoscope is mainly used for intracavity inspection and dissection after the lesion is accessed via a laminectomy. A syringomyeloscope may also be useful in the treatment of chronic subdural hematomas.

Coagulation

Good hemostasis is essential in neuroendoscopy for adequate visualization of structures as well as safety. Hemostasis is achieved either with cautery systems (monopolar or bipolar) or with lasers (discussed in the next section).

Monopolar cautery is the most direct and commonly used method to achieve hemostasis (Fig. 9). The Bugbee Wire (USA) is probably the simplest monopolar cautery, commonly used by urologists as well as neuroendoscopists. The Bugbee Wire without applied cautery current can also be used as a probe to "feel" tissue or membrane (eg, "palpation" of the floor of the third ventricle before fenestration) or to pierce a membrane (eg, third ventriculostomy, fenestration of cyst).

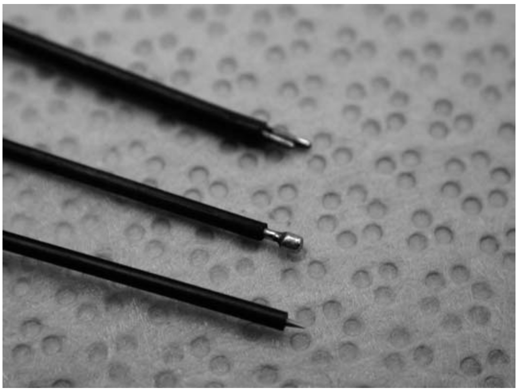

Fig 9. Various coagulation probes.

Slightly more sophisticated monopolar cauteries are available from Cook and Codman & Shurtleff. The Cook system is a number 3 French retractable instrument that is kept within a protective sheath while passing through the working channel. The surgeon squeezes the loop handle to expose the tip as needed. Both round ball and pencil-point tips are commercially available. The Cook electrodes may be used through rigid and flexible endoscopes. Codman & Shurtleff designed the Micro Endoscopic Electrode (ME2), which relies on a retraction mechanism similar to the Cook cautery.

Because there can be a problem with standard monopolar cauteries of burnt tissue adhering to the tip of the instrument, Heilman and Cohen [2] invented the "saline torch" monopolar cautery. With this tool, the electric current is directed through a jet of saline, allowing the surgeon to dissect and coagulate structures without direct contact, even when completely immersed in cerebrospinal fluid (CSF).

Bipolar coagulation is a more precise way of achieving hemostasis with less scatter of current compared with a monopolar cautery. The simplest bipolar electrode is a fork electrode (eg, Aesculap 2.1-mm fork electrode). When using a fork electrode, however, the surgeon cannot pick up tissue, which makes its use somewhat limited. Codman & Shurtleff therefore introduced grasping bipolar forceps 2.5-mm in diameter. These forceps are suitable for coagulation of vessels of no more than 2 mm in diameter. NeuroNavigational offers both 1.0- and 2.4-mm flexible bipolar electrodes. They can be used through rigid and flexible scopes. An advantage of these electrodes is a built-in irrigating channel to decrease adherence of the tissue to the wires. Finally, Clarus manufactures a bipolar cautery that looks like a pencil and has a 30° tip angle. This allows the surgeon better visibility of the cauterized object.

Instruments

Various grasping forceps are commercially available from different manufacturers:

- Cook produces flexible forceps designed for use through rigid and flexible scopes.
- Rat tooth, alligator, and mouse tooth forceps can be used for dissection, enlargement of an opening, and pulling tissues. On a few occasions, the authors have used them with endoscopic scissors to cut and remove an occluded ventricular catheter overgrown by choroid plexus (Fig. 10).
- Cup forceps, two- or three-pronged forceps, and flexible loop retrievals are designed to obtain tissue for biopsy. The design of these instruments facilitates removal or retrieval of tissue fragments. Some of these instruments are intended for single use. Aesculap manufactures similar instruments in flexible and rigid variants. The malleable steering forceps are available from Clarus.
- Another helpful instrument is the Fogarty balloon (Fig. 11). Usually surgeons use number 2 or 3 French catheters, depending on the diameter of the working channel. The Fogarty balloon is used by many surgeons to dilate the opening in the floor of the third ventricle during an endoscopic third ventriculostomy. The advantage of this technique is that the inflated balloon compresses

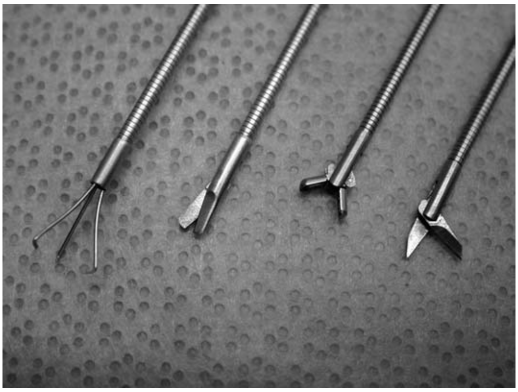
Fig 10. Endoscopic microsurgical instruments (Aesculap, Center Valley, Pennsylvania).

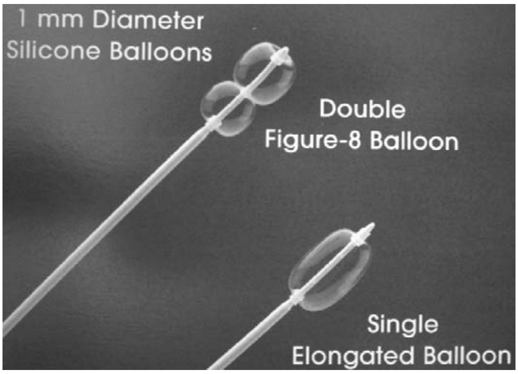

Fig 11. Balloon catheters.

surrounding tissues, constricting bleeding vessels.
- In the past few years, there have been case reports of accidental, often fatal, injuries to the vessels of the basilar artery bifurcation complex [6]. Recently, a new device for perforation of the floor of the third ventricle ("no through perforator") was developed by Grotenhuis and became commercially available from Synergetics (USA). It consists of a 3-mm thick hollow rod with a sharp cutting edge. After suction is applied, the floor of the third ventricle "jumps up" and sticks to the tip of the perforator, leaving the interpeduncular vessels below. The device is turned gently to create a round 3-mm diameter hole. The device seems to improve safety and lower the risks involved in perforation of the floor of the third ventricle.

Lasers

The laser beam is a form of energy used in surgery to cut, coagulate, vaporize, and dissect tissues. Its applications are quite similar to those of electricity; however, the nature of the laser is uniquely different from that of electricity.

Laser is an acronym for light amplification by stimulated emission of radiation. Laser energy can be generated in a plasma tube by a powerful electromagnetic field. Application of this field to some type of gas molecules, such as carbon dioxide or argon, leads to their excitation. Electrons from the excited molecules start moving from one energy state to another. When these molecules drop from an excited to a resting state, a photon (a unit of energy that has a characteristic wavelength) is released. The release of a photon energy unit is called fluorescence. Once a photon hits a neighboring molecule, another photon is released, the wavelength of which is in phase with the first photon. This process, called stimulated emission, is self-perpetuating, because neighboring molecules continue to bombard each other with photons. The mirrors on both tips of the laser tube reflect the emitted photons, increasing the level of movement and energy within the tube until, finally, the beam emerges. On emergence, the beam has the following three features:

- The beam is coherent, because all photons are released in the same phase.
- The beam is monochromatic, because the material emits only a single wavelength.
- The beam is collimated, because the waves emerge parallel to each other.

As a result of these features, a lens is able to focus the light to a fine point, with an extremely high concentration of power density [4,8].

Biologic effects of laser

Application of laser to tissue causes an instantaneous increase in temperature, leading to vaporization of the extracellular fluid and explosion of the cell. Four concentric zones of impact appear as a result of the interaction between laser and tissue:

- Central zone—no cells remain, only burnt debris.
- Vacuolated cells zone—the tissue is composed of nonviable vacuolated cells that retain some structure.
- Edematous zone—some cells in this area are dead, but most of the cells are viable with increased intracellular water content.
- Reversible ultramicroscopic changes zone—although no alterations are seen under light microscopy, some minor histochemical changes are present.

The first two zones are irreversibly dead. The latter two zones are viable and recoverable [4].

Types of medical lasers

Many lasers are available for clinical use, but only two are commonly used in neuroendoscopy because of their ability to work through water and transmit through the miniature fiberoptic cables: neodymium:yttrium-aluminum-garnet (Nd:YAG) and potassium-tetanyl-phosphate (KTP) [4,9,11,12].

Initially, lasers were popular in neuroendoscopy, especially to make the opening in an endoscopic third ventriculostomy [12]. After a few instances of injury to the vessels in the interpeduncular fossa [6], however, laser use significantly declined for safety reasons. Nevertheless, the Nd:YAG laser and, especially, the KTP laser may be useful in endoscopic tumor removal and cyst fenestration. The tissue penetration of the KTP laser is less than with the Nd:YAG laser; its visible light makes it easier to handle, and it is less dependent on the tissue pigmentation, which makes it suitable for dissection of colloid cysts.

Scope holders

Neuroendoscopy can be done either freehand by one or two surgeons (one navigating the scope

Table 3
Advantages and disadvantages of a scope holder

	Freehand	With rigid holder
Advantages	More freedom of movement, particularly when configuration needs to be frequently or continuously changes (eg, tumor removal, inspection of subarachnoid cisterns)	Surgeon has the use of both hands
		Minimizes accidental movements and tremor
Disadvantages	More fatigue for surgeon	More static (inflexible)
	Greater risk of accidental movements	Inconvenient when frequent repositioning is needed

and the other working with instruments) or using a rigid holder. Table 3 describes the advantages and disadvantages of each technique.

Today, there are many scope holders available, such as the Leyla self-retaining retractor, the flexible Greenberg retractor, the Neuroview Scope Holder, and the Unitrac pneumatic holder produced by Aesculap (Fig. 12). The authors have found the latter system particularly helpful, even when operating freehand, because the holder can be used as an easily adjustable hand rest. The device uses the same pressurized gas that powers pneumatic drills.

Fig 12. Unitrac scope holder (Aesculap, Center Valley, Pennsylvania).

Summary

In sum, understanding some of the basic principles of endoscopy and awareness of available resources can potentially be of considerable help to experienced neurosurgeons as well as beginners in selection of the most appropriate tools for different procedures and making cost-effective choices when browsing through multiple commercial advertisements and purchasing new equipment.

Although numerous advantages in science and industry have made it possible to offer a wide variety of neuroendoscopes and tools, we believe the major achievements in this field are yet to occur. This particularly refers to the development of smaller fiberoptic scopes with better image quality and three-dimensional endoscopes and to the invention of more efficient tools for endoscopic tumor removal with the same degree of safety as in open surgery.

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