Instrumentation and Technologies in Endoscopic Ear Surgery

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KEYWORDS

- Endoscopic ear surgery • Microscopic ear surgery • Otologic instruments
- Cholesteatoma

KEY POINTS

- The operating microscope requires wide viewing portals for adequate illumination and visualization of the operative field, contrary to the endoscope, which provides direct vision with illumination to the target field, thus avoiding the need for extra exposure and extra drilling.
- When planning an exclusive endoscopic ear surgery, still the microscope is an essential part of the surgical setting making it ready to use whenever needed. Combining the attributes of microscope and endoscope during surgery is the most efficacious approach.
- Cholesteatoma resection is considered complete only after a final survey with the angled endoscopes is completed, confirming absence of pathologic conditions from all hidden recesses.
- The principal advantage of aspiration instruments is the ability to perform dissection and aspiration maneuvers at the same time overcoming the impact of operating with one hand as imposed by otoendoscopic surgery. The main limit of instruments with suction channels is the possibility of occlusion caused by detritus aspirated during dissection.

Videos demonstrating use of the instrumentation discussed in this article are available at http://www.oto.theclinics.com/

INTRODUCTION

This article covers state-of-the-art devices and instruments specially designated for endoscopic ear surgery. New technologies have stimulated the creation of special endoscopic equipment and microinstruments specially designed to satisfy the

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exclusive requirements of endoscopic ear surgery, which in turn contributes to the progress of the specialty. In addition, these new, specially designed instruments have expanded the indications and refined the surgical skills for this surgery. This, in turn, allows better control of pathological conditions and permits access to previously unreachable or difficult to reach anatomic recesses (ie, sinus tympani, facial recess, and anterior epitympanic recess).

The operating room for ear surgery should contain state-of-the-art instrumentation. The surgeon should be in a comfortable working position during the prolonged holding of the endoscope, which is mounted with the endoscopic video camera. Even when planning an exclusive endoscopic ear surgery, the microscope is an essential part of the surgical setting. The microscope should be supplied with a built-in high-definition camera that allows continuous documentation in parallel with the endoscopic surgery performed, all through a high-definition video monitor. The presence of continuous video monitoring enables the anesthesiologist, the scrub nurse, and others to observe and follow the proceedings of the operation. Recordings can also be used for teaching purposes.

The patient is placed supine on the operating room table in the normal otologic position. The microscope is placed in the sterile field ready to be used whenever needed. The endoscopic tower is placed directly facing the surgeon while the monitor is level with the surgeon's eyes. Because the surgeon is not looking down into the eyepiece of the endoscope and, instead, is looking directly forward at the video screen, proper alignment of these components is essential to keep the surgeon orientated to the surgical field and to ensure a comfortable working position.

STANDARD INSTRUMENTS FOR MICROSCOPIC EAR SURGERY

Besides the standard instruments required for the approach through the soft tissue (eg, scalpels, forceps, and monopolar and bipolar diathermy), specific otologic instruments (**Fig. 1**) include

- Self-retaining mastoid retractors

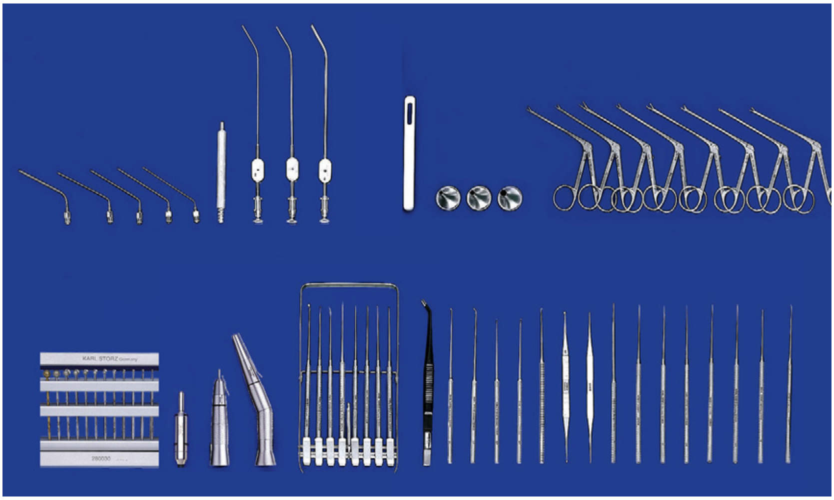


Fig. 1. Standard otologic instruments set used by otologists in all regular microscopic ear surgery. (*Courtesy of* Plester, Karl Storz GMBH & Co, Tuttlingen, Germany; with permission.)

- Instruments for bone work: microdrill, micromotor handles straight and curved, set of different-sized tungsten cutting burrs, and diamond burrs
- Irrigation and suction instruments
- Soft tissue dissectors, large and small scissors, toothed and untoothed forceps, periosteal raspatory.

In general, a full set of microsurgical instruments is required, which are very familiar to practicing otologists:

- Microforceps (microcup and microalligator); microscissors, delicate straight and curved; microhooks of different angles and lengths; needles; elevators, knives of different sizes and shapes (eg, round cutting knife); Plester vertical cutting knife; sickle knives of variable curvatures; Rosen elevator; House curettes, large and small; and so forth
- Suckers and suction-irrigation of different sizes
- Fine suction tips and adaptors with control hole.

ENDOSCOPES AND SPECIAL INSTRUMENTS FOR ENDOSCOPIC EAR SURGERY

Ear Endoscopes

Endoscopes have proved increasing benefit in ear surgery. Incorporating the endoscope into the surgical armamentarium in otology has contributed much to the concept of minimally invasive surgery. This is because the operating microscope requires wide viewing portals for adequate illumination and visualization of the operative field, contrary to endoscope, which provides direct vision with illumination to the target field, thus avoiding the need for extra exposure and extra drilling.

Endoscopes have many proven advantages over the microscope, including

- Wider angle of view
- Better visualization of structures that are parallel to the axis of the microscope
- Visualization of deep recesses and hidden structures (ie, around the corner)
- Ability to visualize beyond the shaft of the surgical instruments.

On the other hand, several disadvantages of endoscopes include[1–3]

- Loss of depth perception and binocular vision
- The inevitable one-handed surgical technique involved
- Need for a strictly bloodless field (meticulous attention to hemostasis is essential)
- Fogging and smearing of the tip of the endoscope
- The mandatory need for reliable physician training
- The cost of equipment.

Rigid Endoscopes

The design of the Hopkins rod-lens system was developed to yield endoscopes of variable length, diameters, and angles of view. The rigid endoscopes commonly used for ear surgery are 2.7 mm, 3 mm, or 4 mm in diameter. All the new endoscopes are now autoclavable. The working lengths are 18 cm, 11 cm, and 6 cm. The larger the diameter, the better the image displays and the more light it can transmit to the operative field. The 0° and 30° angled scopes are the most commonly used, followed by the 45°. Endoscopes with a greater angle, such as the 70°, are difficult and disorienting to work with and are only used for inspection in limited spots, such as the sinus tympani, which may lie very deep in 20% of cases (**Fig. 2**). Recently, new developments in optics have led to the creation of a new generation of wide-angled endoscopes with smaller diameters that provide better quality images.

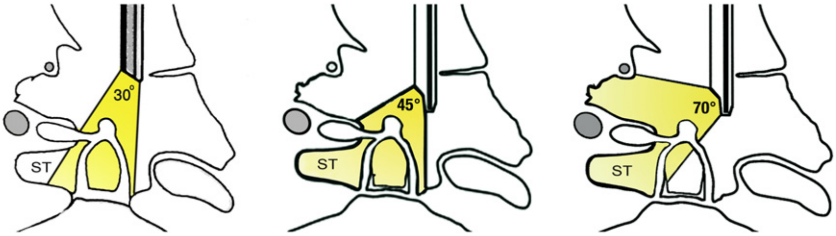


Fig. 2. The sinus tympani (ST) and pyramidal eminence area showing the field of view of different angled endoscopes and the degree of visualization each endoscope can provide.

The 0° endoscope provides all of the imaging needed to perform the major steps of any endoscopic operation. The optics allow near-complete exposure of most of the field and pathologic condition. However, the extent of visualization under the 0° endoscope is limited by its optical capabilities. The distal lens of the otoscopes must be cleaned with an antifog solution before each application.

Practically, in cholesteatoma surgery, once cholesteatoma resection under the 0° endoscope is deemed complete, it is replaced with the angled 30° or 45° endoscopes. By advancing the angled endoscope and rotating it in clockwise and counterclockwise directions along its longitudinal axis, all middle ear recesses are visualized and any hidden pathologic conditions can be detected and removed. Cholesteatoma resection is considered complete only after a final survey with the angled endoscopes is completed, confirming absence of pathologic condition. A 70° endoscope may also be used in this examination; however, in most cases, the information obtained by the 30° or 45° lens is sufficient to identify any residual pathologic condition.[4–7]

Instruments

The development of special equipment and instruments for endoscopic ear surgery is based on the International Working Group on Endoscopic Ear Surgery (IWGEES) experience of more than 15 years performing endoscope-assisted and/or exclusive endoscopic ear surgery. Adapting and refining regular microinstruments to include longer, more slender shafts with single or double curvatures and smaller microtips have been essential for endoscopic ear surgery.

Major innovation of highly sophisticated technologies such as xenon light sources, high-resolution cameras and monitors, digital processors, documentation, and lens irrigation systems have complemented the advances in endoscopic technology and stimulated the creation of dedicated endoscopic equipment and microinstruments specially designed to fulfill the unique requirements of endoscopic ear surgery.

Practically, endoscope-assisted and fully endoscopic ear surgery require the standard otologic microinstruments, familiar and used by any otologist, and the specially modified and newly designed endoscopic ear surgery instruments. A basic set of instruments, based on the IWGEES experience, used exclusively for endoscopic ear surgery is now available.[2] It includes sets of curved shaft dissectors and sharp hooks, sets of curved suction cannulae, sets of curved curettes, and sets of curved cupped forceps with 10 cm working length. Most recent are the newly designed instruments incorporating suction into the shaft, facilitating dissection with one hand while the other hand holds the endoscope. The best example of this is the round cutting knife with suction shaft (**Fig. 3**).

Classic microscopic ear surgery instruments are usually straight shaft or mild curve shaft but, because endoscopic ear surgery necessitates working with the angled

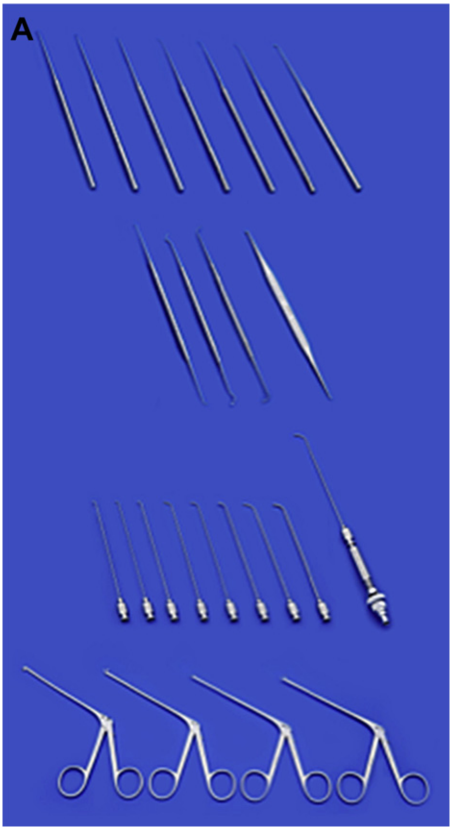


Fig. 3. (*A*) New instrument set for endoscopic ear surgery according to the IWGEES. (*B*) Newly invented suction cannulae, straight, with angled tips of different angulations and lengths. They have diameters ranging from 0.8 mm to 1.6 mm and a length of 10 cm. All are Luer-Lok to be mounted on the Fisch adaptor or the turning adaptor. A rotating adaptor is essential for easy manipulation of cannulae with angled tips. The choice of diameter for these reusable cannulae provides extra comfort for surgeon to choose the optimum instrument for the task. (*C*) Incorporating suction into the shaft of endoscopic microinstruments is a major modification that will help the single-handed surgeon overcome bleeding while dissecting or manipulating tissues and holding the endoscope with the other hand. The round cutting knife, diameter 3 mm, with suction shaft is easy to handle due to rotatable tubing connector, length 19 cm. (*D*) Set of four endoscopic fine-cupped forceps, working length 10 cm, strongly curved. Directions: right, left, backward 90°, and upward 45°. (*E*) Set of fine sharp hooks and elevators, 90°, all with strongly curved shaft and of different directions: right, left, and backward. The presence of the curve on the shaft of the instrument mandates the need for different directions; therefore, the newly designed endoscopic instruments handles are marked to allow easy identification of the direction of each instrument: one marking for right, two markings for left, and three markings for backward. These marks on the handle avoid confusion and facilitate handling of the correct instrument. (*F*) Ear hooks, sharp, 90° right, left, and backward with strongly curved shaft. (*G*) Newly designed endoscopic instruments: Elevators 90° right, left, and backward with strongly curved shaft (*left*). The presence of the curve on the shaft of the instrument mandates the need for different directions. These elevators enable atraumatic dissection of the cholesteatoma matrix from over vital middle ear structures (*right*). (*H*) Set of ear curettes of different sizes with bent shaft to facilitate working under angled vision endoscope. Single-ended curette with curved shaft, double-ended curette with 90° curved shaft, and the standard House double-ended curette. Double-ended 90° curved shaft cleaning the anterior epitympanic recess endoscope is placed transcanal (*lower left*). Double-ended 90° curved shaft cleaning the under surface of the scutum transmastoid (*lower center*). Single-ended curved curette cleaning the under surface of the scutum transcanal (*lower right*). ([*A*] *Courtesy of* Karl Storz GMBH & Co. KG, Mittelstraße 8, D-78532 Tuttlingen, Germany; with permission.)

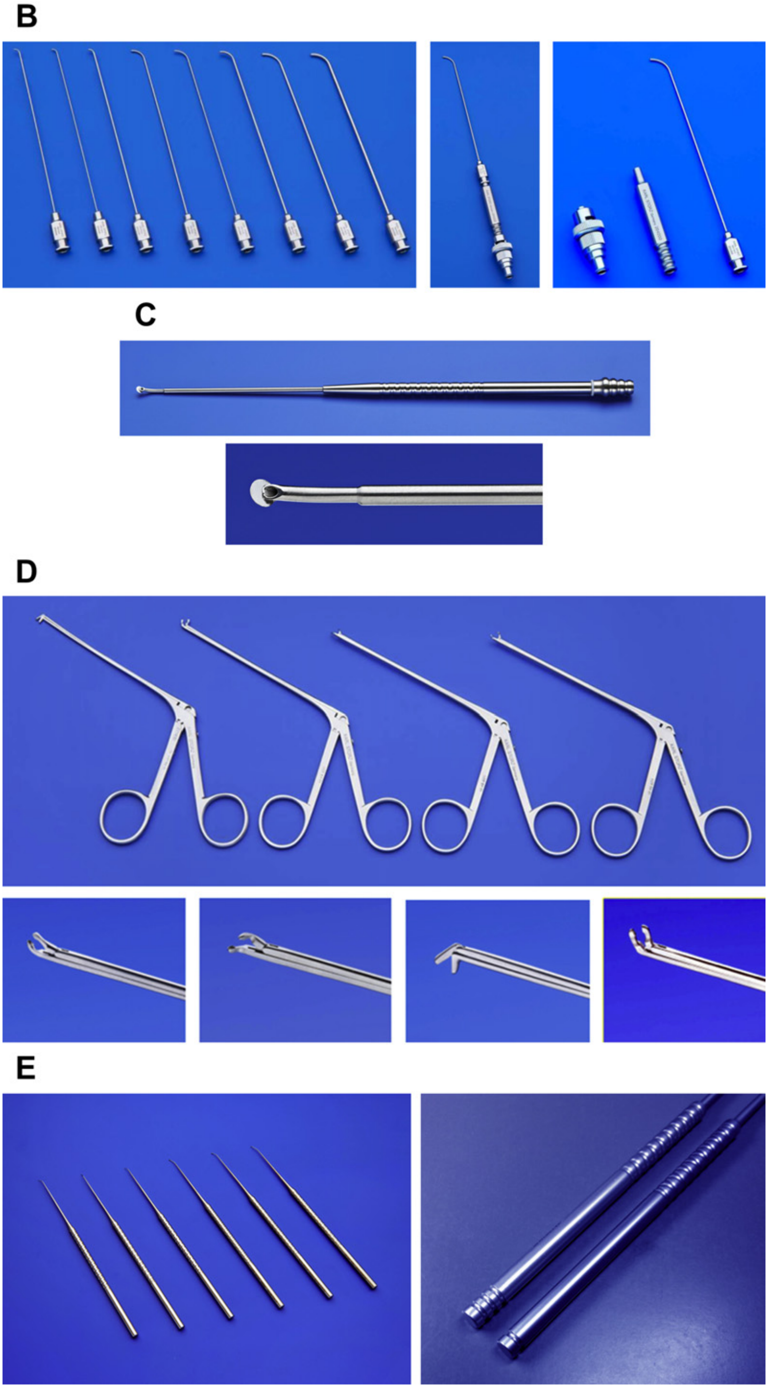


Fig. 3. (*continued*)

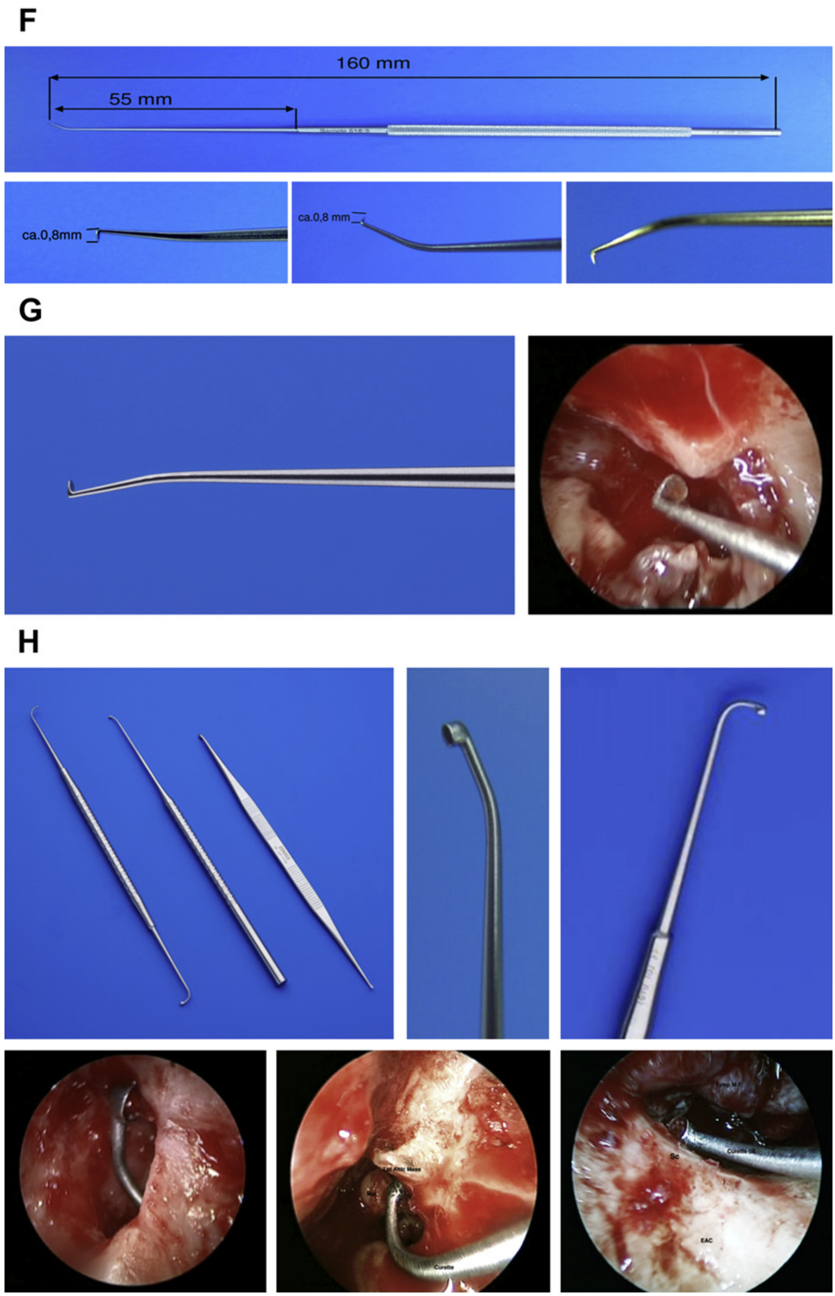
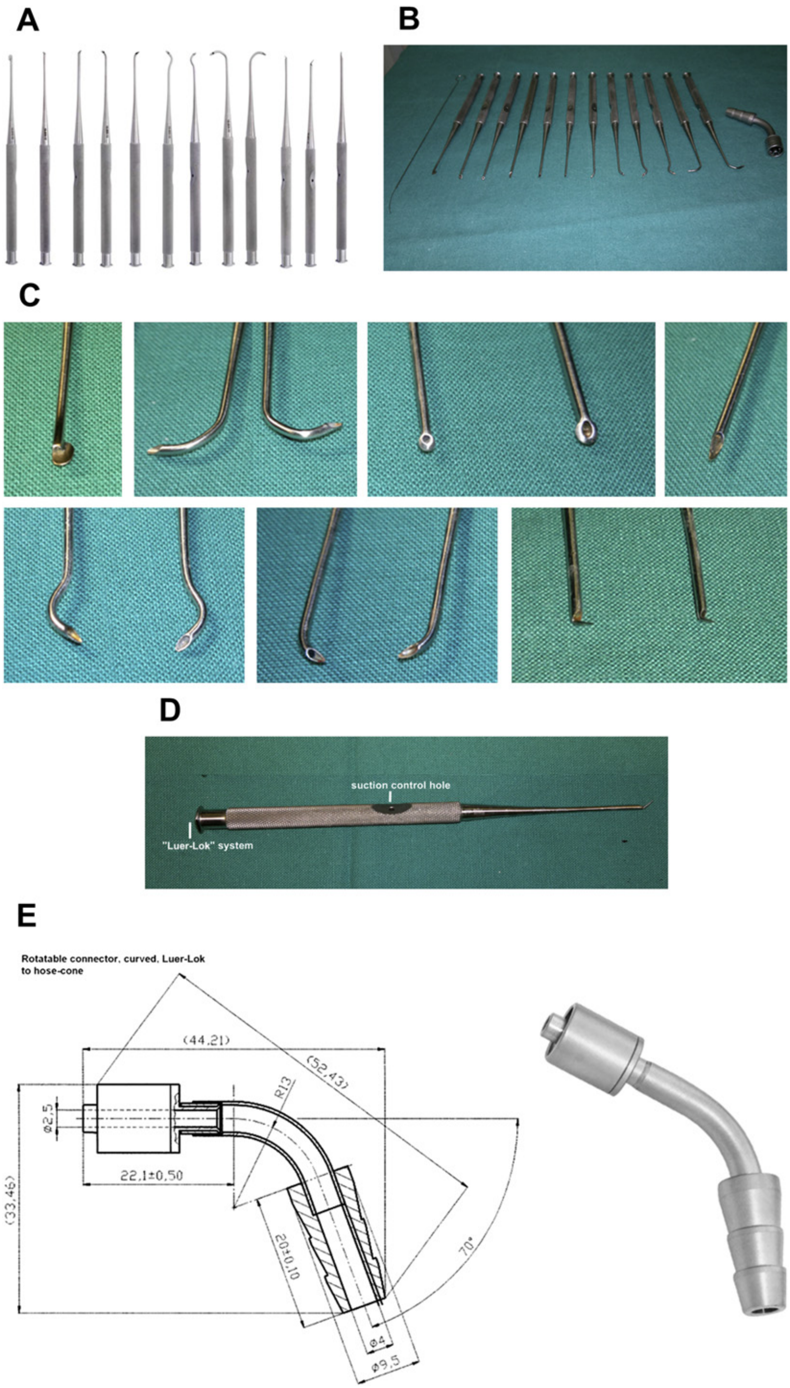


Fig. 3. (*continued*)

30° or 45° scopes (see **Fig. 2**), instruments should be fashioned accordingly with a single-bend or double-bend shaft or significantly curved shaft. This allows ease in reaching into the hidden recesses of the middle ear without the need for extra drilling merely for the sake visualization and instrument handling.


A
B
C
D
suction control hole
"Luer-Lok" system
E
Rotatable connector, curved, Luer-Lok
to hose-cone
(44,21)
(52,43)
R13
Ø2,5
22,1±0,50
(33,46)
20±0,10
70°
Ø4
Ø9,5

Because of the growing indications for exclusive endoscopic surgery, and because major steps are performed under angled endoscopic control, the need to modify more instruments to adapt for the angled vision endoscopic surgery (30° and 45°) proves essential.[8] The IWGEES has worked extensively to create highly specialized instrument sets specially designed for endoscopic ear surgery. More instruments specially adapted for endoscopic ear surgery are now developed. Miniaturization of some of the already existing endoscopic sinus surgery instruments is in progress to adapt for endoscopic ear surgery. Adding curvature to the shaft of microinstruments proves essential to allow the instrument to reach into the deep hidden recesses and make it possible to remove pathologic conditions "around the corner." Once the instruments acquire curved shafts, the instruments require working direction (ie, right, left, and backward). To facilitate handling of instruments of different directions, handles are marked according to the direction of the instrument tip. For instance, there is one mark for right-sided, two marks for left-sided, and three marks for backward tipped (see **Fig. 3**E). Curved forceps with 10 cm working length are also provided to improve surgical maneuverability.

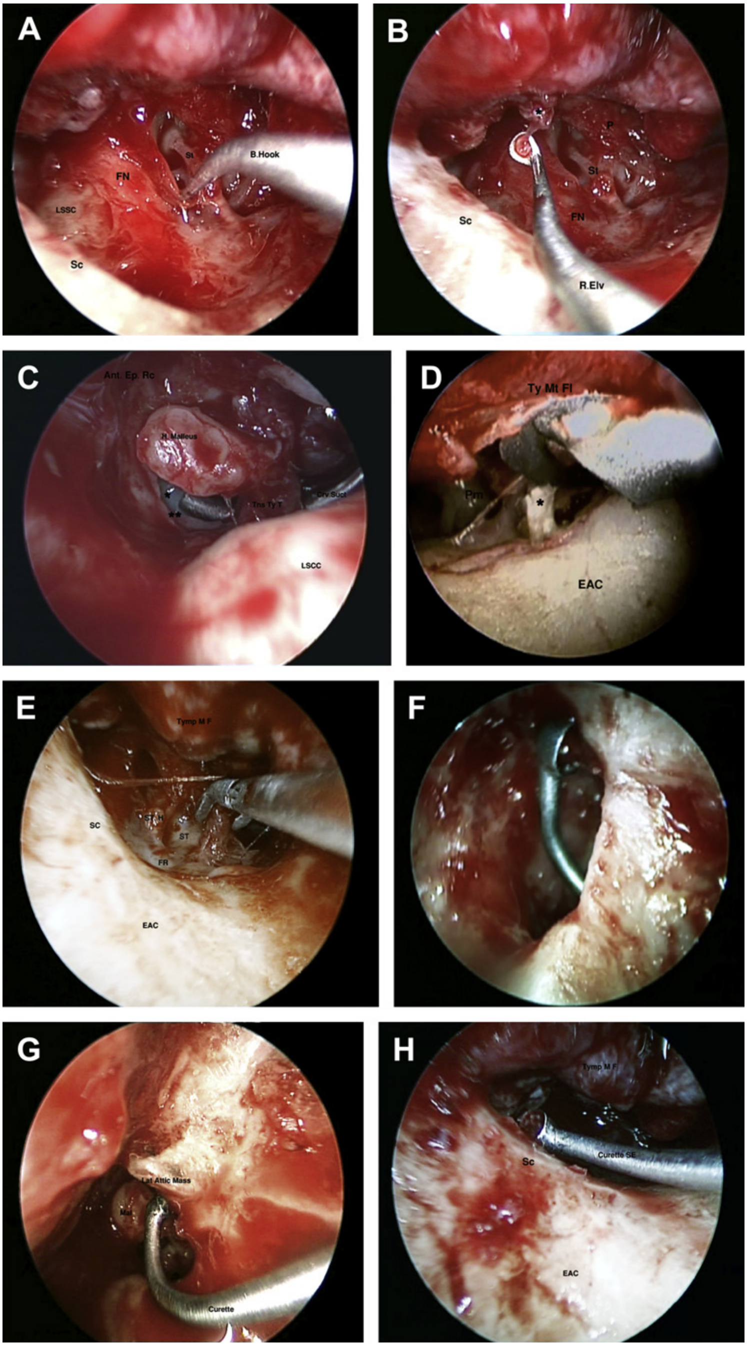
Finally, incorporating suction into the instrument shaft is considered one of the most important modifications that enable the single-handed surgeon to work in a clean bloodless field. Different modifications were provided by different companies (eg, the round cutting knife with suction shaft; see **Fig. 3**C). Many other attempts were introduced to overcome the limits of single-handed endoscopic surgery. Most impressive was the instrument set developed by Professor Giuseppe Panetti in which he imagined a surgical instrument (**Fig. 4**A–D) that has the same shape and length as the traditional one but features a suction channel. Each instrument can be divided in three components:

1. Operative distal extremity
2. Handle with suction control hole
3. Proximal extremity provided with Luer-Lok connection.

The main limitation of this instrument is the possibility of occlusion caused by detritus aspirated during dissection. At the same time, the facility of instrument exchange minimizes the impact of this inconvenience.

The principal advantage of aspiration instruments is the chance to perform dissection and aspiration maneuvers at the same time. This reduces the impact of operating with one hand as imposed by otoendoscopic approach. Dissection operations turn out to be more efficient as a result of the aspiration capability of the instrument. Blurring, as well as blood spots occurring on the endoscope's extremity, which are the most

Fig. 4. (*A*, *B*) The Giuseppe Panetti instrument set characterized by the same shape and length as the traditional set but featuring a suction channel. (*C*) Each instrument presents a different "operative distal extremity," which recalls the most common dissection instruments shapes for the middle ear (eg, a pair of dissectors for tympanic sinus, lenticular bistoury, two lengths curved hook, 45° angled needle). Each extremity is provided with suction opening. (*D*) The intermediate portion in each instrument consists of a handle with a suction control hole. This allows a regulation of instruments aspiration capability. Proximal extremity is provided with a Luer-Lok connector that permits a rapid change of instruments depending on surgeon's needs and in case it gets occluded during dissecting maneuvers. (*E*) The connector is curved, 5 cm, 70° angled and is provided with a rotating distal extremity with a complementary Luer-Lok system. This meets specific ergonomic requirements, ensuring the maximum reduction of attrition to the weight of aspiration tube where joint's proximal extremity is hooked. This makes the instrument handle particularly comfortable and makes dissecting maneuvers easier.


A
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common inconveniences, can be easily removed through physiologic solution washes, assuring a constantly clean operative field without losing fluidity of surgical gestures.

The similarity between the newly designed endoscopic suction instruments and the classical otological instruments make it possible for all otology surgeons to work with ease, thus contributing to wider usage of the endoscopic procedure.

To illustrate the use of new instruments during endoscopic ear surgery, multiple endoscopic views are presented in **Fig. 5**). Videos are also presented that illustrate the technical use of these specially designed endoscopic ear instruments (Videos 1–6).

ADVANCED TECHNOLOGIES USED IN OTOLOGY SURGERY

The following advanced technologies have improved otology surgery:

1. High-definition digital cameras attached to the telescope project images onto one or several monitors. The three-chip cameras and, recently, the high-definition, fully digital cameras produce excellent quality images and feature automatic controls for color, exposure, white balance, and digital contrast enhancement. The Image 1 supplied by Karl Storz instantly converts optical images to digital with improved imaging on all digital recording and display devices. It offers the resolution and light sensitivity necessary for the highest digital image quality. The illumination is generated by a powerful cold-light source and transmitted to the endoscope via a fiber-optic light cable of 180 cm length. The different types of light sources (halogen, xenon, LED) offer light of varying brightness. Xenon is currently preferred.

Fig. 5. Endoscopic ear surgery. (*A*) Right ear view using 30° endoscope. Backward sharp hook (B. Hook) cutting adhesions between the stapes (St) and the facial nerve (FN). Notice the stapes (St), the promontory (P) and the scutum (Sc). As for the asterisk please add it in the context of the phrase: Right ear view using 30° endoscope, Right elevator (R.Elv) dissecting granulation (*) and cholesteatoma from over the facial nerve (FN) (*B*) Right ear view using 30° endoscope. Right elevator (R. Elv.) dissecting granulation and cholesteatoma from over the facial nerve (FN) and cochleariform process. Notice the lateral semicircular canal (LSSC), the stapes (St), and the scutum (Sc). (*C*) Right ear showing transmastoid endoscopic view using 30° scope, 3 mm diameter. The anterior epitympanic recess with the head of malleus attached medially by the tensor tympanic tendon is perfectly visualized. The curved suction (Crv. Suct.) cannula passing transcanal, cleaning the orifice of the eustachian tube (*asterisk*), is seen through the opening created after disrupting the tensor tympani fold. Edge of the tensor tympani fold (*double asterisk*). ant Ep Rc, anterior epitympanic recess; LSSC, lateral semicircular canal. (*D*) Left posterosuperior retraction pocket cholesteatoma. The round cutting knife with suction shaft used to dissect the tympanomeatal flap (Ty Mt Fl) is seen retracting the meatal skin and entering the middle ear. Whitish cholesteatoma matrix is seen in the retrotympanum (*asterisk*). Pm, Promontory. (*E*) Right ear view using 30° endoscope. Left-curved fine cupped forceps with 10 cm working length removing granulation tissue from over the sinus tympani (ST). Stapes head (ST H) attached by the stapedius tendon. EAC, external auditory canal; FR, facial recess; SC, scutum; Tymp MF, tympanomeatal flap. (*F*) Left ear view using 30° endoscope. Double-ended, strongly curved curette is used to clean the anterior epitympanic recess. Notice the double-approach surgery as the endoscope is placed transcanal while the curette is passing transmastoid. EAC, external auditory canal; FR, facial recess; Sc, scutum. (*G*) Right ear showing transmastoid endoscopic view using 30° scope, 3 mm diameter. Double-ended curette, 90° curved shaft while cleaning the under surface of the lateral attic mass (Lat. Attic Mass). The strongly curved curette allows the surgeon to remove pathologic conditions in deep, difficult to reach spots. Mal, head of malleus. (*H*) Right ear view using 30° endoscope. Single-ended, strong curved shaft curette (Curette SE) used to clean the undersurface of the scutum (Sc). EAC, external auditory canal; Tymp MF, tympanomeatal flap.

2. High-definition digital monitors, data management, and documentation are now considered standard equipment whenever endoscopic ear surgery is performed. The digital documentation system, Advanced Image and Data Archiving HD (AIDA), provides convenient image, video, and audio archiving of important stages and results of a procedure for patient and scientific documentation.
3. Microdrill handpieces, attachments, and burrs are used to perform different functions during middle ear surgery in combination with different sizes curettes. For endoscopic ear surgery, the pen-style, compact, powerful, lightweight, high-performance microdrills provide the balance and maneuverability that enable the surgeon to work in tight spaces. Also, the microdrill attachments are tapered to provide improved visibility of the cutting or diamond burrs at its tip during surgery.
4. Piezosurgery, specially designed for bone dissection, is manufactured by Mectron.[9] Piezosurgery, though it does not replace the micromotors for bone drilling, offers the state of the art in bone surgery. The piezoelectric ceramic disks contained in the Piezosurgery Medical handle transmit the microvibration to special inserts designed for each surgical technique. It has the advantage of minimal damage to the soft tissue, maximum surgical precision, blood-free surgical site, and maximum intraoperative visibility. The very fine movement of the cutting inserts (micrometers) enables maximum intraoperative control. It allows bone cut with only 0.3 to 0.6 mm width with no bone necrosis. The wide range of surgical inserts makes it easy to use in different specialties including otology and endoscopic ear surgery.
5. Vesalius (Telea Electronic Engineering)[10] is a special monopolar and bipolar output device that enables the surgeon to perform surgery with an extremely delicate approach and respect of both tissues and biologic structures. Quantum Molecular Resonance is named for the particular way the energy is transferred to the biologic tissue in the form of high frequency electrical fields that interact with the tissue itself. The cutting effect does not depend on an increase of the temperature but, instead, on the breaking up of cells due to the induced resonance effect. In the cutting mode, the temperature rises to 45°C. The coagulation is also obtained by using the same resonance while the energy is transferred. Importantly, the cut is not a consequence of the high heat produced in the tissue, as happens for standard electrosurgical and radiosurgical units. Instead, it is caused by the breakage of the molecular bonds and it is, therefore, obtained without temperature rise. In fact, the temperature rise is very modest at about 63°C, which sufficient to trigger the coagulation via protein denaturation process; the cellular necrosis is avoided. As a consequence, the cut and coagulation performed by Vesalius is extremely precise, delicate, and without thermal damage. It is supplied with a different set of middle ear probes specially designed for endoscopic middle ear surgery to allow fashioning of the tympanomeatal flap and possible dissection of cholesteatoma from over ossicles and epitympanic compartments.
6. The advantages of lasers in middle ear surgery for tissue removal without mechanical trauma have long been recognized. Flexible fibers allow delivery of the laser to the recesses of the temporal bone and are now used widely in the eradication of cholesteatoma.[11,12] In current practice, the principle advantages are in eradicating cholesteatoma,[13] performing stapedotomy, and, occasionally, releasing of congenital ossicular fixation (**Fig. 6**). The KTP laser is a valuable tool in endoscopic middle ear surgery that improves the surgeon's ability to remove cholesteatoma effectively. The principle advantage of the laser is in removal of residual matrix from hidden recesses, such as the subpyramidal space or supratubal recess. Such narrow areas can be inspected effectively with angled endoscopes, but conventional dissectors and forceps do not easily permit removal of retained cholesteatoma matrix without

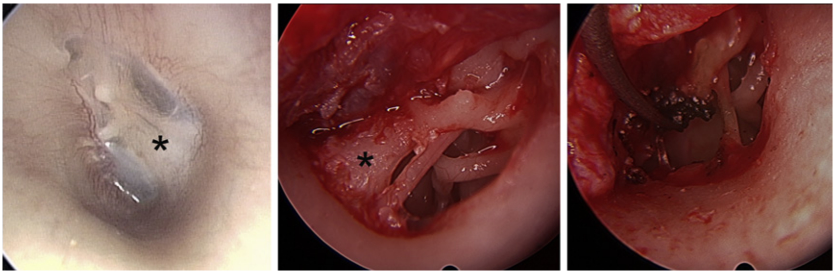

Fig. 6. Endoscopic images of congenital fixation of the left malleus handle from a tympanic bony plate (*asterisks*). KTP laser was used to free this plate from the malleus handle without torsion or mechanical displacement that could have caused cochlear injury. Four-tone average air conduction threshold improved from 41 to 18 dB HL, and bone conduction from 9 to 5 dB HL. Preoperative image, anatomic orientation (*left*). Tympanomeatal flap elevated, surgical orientation (*center*). Bony plate divided, surgical orientation (*right*). HL, hearing level.

destructive bone removal. The KTP beam can be guided into these areas because of its fine fiber carrier, which allows for disease removal by a conservative approach. Use of the laser to remove granulation tissue is of particular benefit with endoscopic surgery because bleeding into the field is minimized. Addition of the KTP laser to endoscopic middle ear surgery is expected to help reduce residual disease and improve hearing outcomes by facilitating ossicular preservation.[14] It is thus an important adjunct in the endoscopic surgeon's armamentarium.

In cholesteatoma surgery, laser is effective at ablating visible and submicroscopic remnants of cholesteatoma matrix (video 7), shrinking granulation tissue (video 8), and dividing mucosal folds (video 9). Mucosal surfaces heal well after laser has been applied to the middle ear and mastoid as shown in (**Fig. 7**). The main risk is

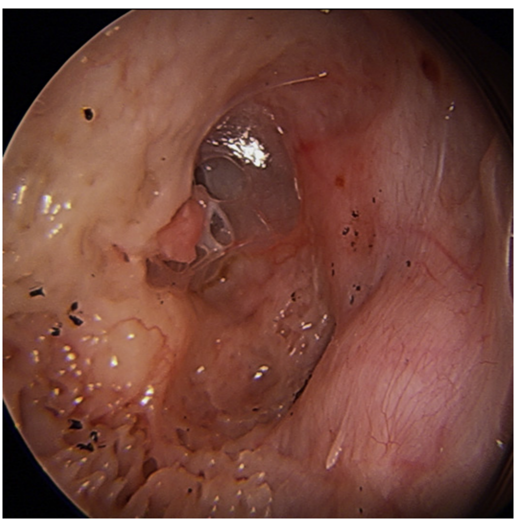

Fig. 7. Endoscopic view of left mastoid cavity at second stage of intact canal wall tympanomastoidectomy. Specks of carbonization indicate the area where KTP laser was previously applied 1 year previously during the first stage of surgery. The mucosa and bone have healed well and the cavity is well ventilated.

inadvertent facial nerve injury[15] and, for this reason, care must be taken not to apply laser energy close to the nerve.

Practical points to consider when using KTP laser in the middle ear include the following:

- KTP is transmitted by a fiber that can be used alongside the endoscope. The fiber is slightly flexible so the tip can be adjusted for use with angled endoscopes.
- A filter can be placed in front of the camera, which filters the burst of light that would otherwise obscure the view.
- Atraumatic removal of granulation tissue, matrix, and perimatrix from ossicular chain is possible.[16] It is claimed that it is less damaging to cochlea than mechanical dissection of ossicles.[12]
- A power setting of 1 W can be used with a defocused beam to paint areas where cholesteatoma is adherent to reduce the presence of submicroscopic deposits of residual cholesteatoma (not near the facial nerve).
- Lower power settings are effective at ablating residual matrix from the ossicles (300–400 mW).
- Smoke does not need clearing with two handed microscope-guided surgery. In one-handed endoscope-guided surgery, an assistant can hold a sucker in the meatus (although this is simplest, it can be awkward, and there is danger of accidental advancement of the sucker into the stapes); or attach it to the endoscope or the laser probe with Steristrips.[17]

SUMMARY

State-of-the-art devices and instruments have been specially designated for endoscopic ear surgery, contributing to the progress of the specialty. These instruments help expand the indications and refine the surgical skills for this surgery, allowing better control of pathological conditions and permitting access to previously unreachable or difficult to reach anatomic recesses.

SUPPLEMENTARY DATA

Supplementary data related to this article are found online at http://dx.doi.org/10.1016/j.otc.2012.10.005.

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