Springer Handbook of Medical Technology

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19. Endoscopy

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Endoscopy has an established position in modern medical diagnosis and treatment. The advantages of endoscopy are important for all those involved and are decisive for the success we enjoy today: for the doctor it means improved diagnosis and treatment; for the patient it means minimally invasive approaches, reduced trauma, reduced risk of infection, quicker wound healing, and often, shorter stays in hospital; and as a result for the hospital and society this translates into reduced costs. This general statement can also be looked at in considerably more detail for individual indications, but that is not the purpose of this chapter. The age of purely diagnostic endoscopy is far behind us. Endoscopy is either replacing open surgery and microsurgical procedures or now exists in competition with them in a wide range of fields. In this respect, medical and medical technological advances are occurring continuously, and there appears to be no end to this development in sight. The field is seen as highly innovative with new approaches emerging continually, of which, however, only some will prove to be both a financial and a clinical success.

19.1 Basics

Endoscopes can either be introduced through natural orifices (mouth, nose, ear, esophagus, trachea, urethra, rectum, vagina or even the tear duct in the eye or the lactiferous ducts of the breast) or via small, artificial incisions in order to reach the organs of the abdominal cavity or enter joint spaces.

Successful endoscopic concepts always reflect the challenge between the maximum possible reduction of trauma associated with the surgical approach, by reducing the external diameter of instruments on the one hand, and, on the other, the maximum image quality and possibility for manipulation and interventions which favor larger telescopes and large instruments or working channels. In addition, the general parameters are defined by human anatomy and technological capacity.

19.1.1 Terminology

Endoscopy concerns the visualization of concealed body cavities, as is clear from the Greek roots of the word ἐνδοσ (*endos*, Greek: inside) and σκοπεῖν (*skopein*, Greek: to look). Endoscopy is a medical technology and not a clinical speciality in its own right. Today it is daily routine in many medical fields [e.g., gastroenterology, abdominal surgery, urology, gynecology, sports medicine, ear–nose–throat surgery (ENT), pneumology] – in fact there are only a few fields in which endoscopy is not represented.

The names of different endoscopic procedures are generally composed of the term for the organ which is the object of the investigation, followed by the suffix "scopy", e.g., gastroscopy, laparoscopy, cystoscopy, hysteroscopy, arthroscopy, laryngoscopy, and bronchoscopy, to give a selection of examples from the fields listed above.

Seen from this angle, names such as *resectoscopy* and *videoscopy* are inappropriate, although we encounter them from time to time. These terms are derived from instruments or types of endoscope. In this case, the instrument concerned is the resectoscope (an instrument from urology and gynecology), or the videoendoscope, which can now be found in a wide variety of applications and describes an endoscope which, amongst other things, is equipped with a distal image sensor.

The term *keyhole surgery* is often employed in scientific journalism as a striking term for endoscopy, which restricts the possibilities of endoscopy to purportedly secretive observation. On the contrary, thanks to the modern possibilities for using images in the training of doctors and when informing the patient, endoscopy has, in fact, become very transparent and with its diverse treatment possibilities has advanced far beyond the boundaries of optical diagnosis. We regard the term endoscopy as being established; the surgical element of endoscopy is often referred to as minimally invasive surgery (MIS). We thus use these terms throughout.

19.1.2 Endoscopy and the Strengths of Optical Perception

When we are faced with a complex situation, the first thing we want to do is *to get a picture* of it. When we have correctly understood something, we say "I see." This idiomatic representation brings the optical sense and our sight into the focus of our perception. It is not merely coincidence that sight is our most important sense. The retina is one of the few places in the body where the cellular bodies of neurons can be found outside of the actual central nervous system. Based on the image processing which occurs in the retina, we can regard this from a technical point of view as a type of optical coprocessor.

For the purposes of our discussion, optical image formation is based in principle on three components [19.1]:

1. illumination with visible light,
2. an object with characteristic absorptive and reflectance properties, in special cases with fluorescence and other effects; these properties modulate the illumination light,
3. observation with photosensitive and color-sensitive sensors, either our eye or a semiconductor sensor, and processing in the retina and in the brain or technical means of image processing.

This list already identifies two central components of endoscopy for us: high-quality illumination and imaging. The details of the endoscopic image chain are discussed in Sect. 19.2.3.

Magnification and Resolution

With the naked human eye we can see objects of approximately 0.1 mm, using optical aids such as a microscope this can even be extended to view structures in the submicrometer range. Special endoscopic procedures can be used to view structures measuring just a few micrometers. In principle, it can be asserted that with modern endoscopic equipment the accuracy of detail and resolution of the image considerably surpasses the perception during open surgery and thus allows the doctor to work more precisely. This is also due to the characteristic that, at a short distance from the object, endoscopes have a magnifying effect. Furthermore, this advantage is reinforced by the continuous improvement of optical and electronic systems, most recently by the introduction of high-definition (HD) camera systems.

The resolution of an endoscopic system depends on the optical parameters. As a result, image enlargement with optical zoom is associated with an increase in the information gained, while a *digital* zoom is not.

Color Vision

Our color vision provides us with an additional dimension that other imaging procedures such as magnetic resonance imaging and ultrasound do not offer. In normal observation conditions, the human eye cannot differentiate between more than 256 grey levels (8 bits) [19.2], whereas the endoscopic image delivers 10 bits in three color channels. This is particularly important with respect to the fact that the doctor must differentiate between a multitude of red tones in tissue.

This is not to be confused with procedures such as color Doppler ultrasound, in which a further measured variable (flow speed) is superimposed over the grey value image via a false-color representation.

Significance of Surfaces

One obvious weakness of light is that it cannot penetrate tissue deeply and can only visualize surfaces. Our internal organs are composed of manifold internal surfaces, which have been made accessible by the use of endoscopes. In addition, a multitude of pathological changes occur on surfaces, making endoscopy a very effective diagnostic and treatment procedure. A carcinoma, commonly referred to as cancer, is a malignant tumor originating in epithelial tissue, which can be found on the (internal or external) surface.

It is important to understand that surface structures can be visualized considerably better and more precisely with optical procedures than with other imaging procedures thanks to the color rendering and the excellent spatial resolution. As a result, with the current technical possibilities, all procedures of virtual endoscopy via computed tomography (CT) and magnetic resonance using interpolation procedures only appear to be as accurate but are in practice considerably inferior to optical procedures.

Perception and Processing of Visual Stimuli

The biological aim of sight is to recognize objects, dangers, and surroundings, not primarily to act as an optical or spectral recording system. When it comes to recognizing what is visible in an image, the human observer is usually superior to technical procedures.

Goethe, a well-recognized German poet, focused intently on colors, sight, perception, and their complex interaction. His argument of cause and effect, i.e., *one only sees what one knows*, was expanded by *Berci* in his ground-breaking work *Endoscopy* [19.3] in 1976 into *what ones sees should become known and documented*. Even today this remains a central pillar of endoscopy. Image processing and recognition is one of the tasks for which we are still searching for a final solution.

However, current research is also focusing on the advantages of optoelectronic and biophotonic procedures over pure imaging with white light in order to achieve better, i. e., more objective, tissue differentiation [19.4].

Classification

Information which we cannot see, such as ultrasound, magnetic fields, and x-rays, must first be converted into something that we can understand. The preferred solution is an optical image, which is why these procedures are often referred to as medical imaging modalities, even though the original information cannot be *seen* at all, but is rather measured. Endoscopy is generally not defined as an imaging modality in standard nomenclature, although based on modern endoscopy this is a point which could definitely be discussed further.

19.1.3 Challenges

Sight

Endoscopy has deprived the doctor of a direct view of the site of examination or operation. Although in the meanwhile resolution has been improved to such an extent that it considerably surpasses conventional sight, stereoscopic vision remains limited.

Haptics

The digital (*digitus*, Latin: finger) feeling and *grasping* of organs with the fingers is another important sense which could be relied upon in open surgery but which is now translated by long instruments and thus barely perceivable.

Manipulation

The space available to move and manipulate is restricted by the choice of access; appropriate planning and experience are required to compensate for this. Complex procedures are sometimes performed with expensive telemanipulation systems, although this can normally not be justified from an economic point of view. In addition, the desire for miniaturization restricts the size of instruments (e.g., forceps), which can result in longer interventions.

Conclusion

The restrictions placed on the senses of sight, touch, and to a certain extent, smell as well as the restricted manipulation possibilities which a doctor is prepared to accept in endoscopy must also be clear to the engineer when designing new instruments so as not to broaden this deficit even further. The target should be to open up possibilities with endoscopy which were previously not available.

19.1.4 History

The desire to look into concealed body cavities goes back thousands of years. There is written evidence that instruments for proctoscopy were in use in ancient Egypt [19.5], and specula have been retrieved from Pompeii dating from the first century AD. Technical possibilities and medical advances were mutually dependent. A few milestones are listed here to serve as examples; more detailed information can be found in, for example, *Reuter*'s work on endoscopy [19.6]:

1806 Philipp Bozzini builds the first instrument for introducing light into body orifices, his so-called *Lichtleiter* (light conductor), in Frankfurt (Germany) [19.7].

1868 Adolf Kußmaul (Freiburg, Germany) performs the first gastroscopy on a sword swallower using an open tube and a candle.

1877 Max Nitze (Berlin, Germany) uses an optical lens system and a glowing platinum wire for illumination.

1902 Georg Kelling (Dresden, Germany) performs diagnostic laparoscopy on two female patients.

1912 The Dane Severin Nordentoft reports for the first time on knee arthroscopy. Kenji Takagi (Tokyo) begins performing arthroscopy with a cystoscope in 1919, and Otto Bircher in 1921 in Aarau (Switzerland).

1929 Heinrich-Otto Kalk (Berlin, Germany) is seen as a true pioneer of diagnostic laparoscopy through his work.

1934 John C. Ruddock (Los Angeles, CA) describes laparoscopy as a valuable diagnostic method.

1950 Publications on gynecological laparoscopy begin to appear: Raoul Palmer (Paris, France, 1950), Hans Frangenheim (Wuppertal, Germany, 1958).

1958 Basil J. Hirschowitz presents a flexible gastroscope, which still features a distal light bulb (University of Michigan, MI, USA).

1959 Harold H. Hopkins (Reading, UK) patents a rod lens system that dramatically improves image transmission in endoscopes; the invention is introduced in rigid endoscopes in 1965 by Karl Storz.

1963 Karl Storz introduces illumination with glass fibers in the endoscope as a new technology (cold light).

1985 Erich Mühe in Böblingen (Germany) performs the first laparoscopic cholecystectomy (removal of the gallbladder).

19.2 Endoscopes and Endoscopic Accessories

Modern endoscopy systems are composed of a variety of components. Basically, these core components serve to generate light and illuminate the intracorporeal treatment area optimally while producing images which are then relayed out of the body and visualized optimally. Alongside purely endoscopic visualization, numerous instruments and devices are also required to enable minimally invasive treatment. In principle, one differentiates between rigid and flexible endoscopes.

19.2.1 Light Sources and Illumination

Light transmission has been performed in both rigid and flexible endoscopes via optical fiber bundles since the 1960s. Physically, the transmission of light via a light conducting fiber is based on the principle of total internal reflection between the core and the sheath of the individual glass fiber. Halogen, halide, and xenon light sources are employed as extracorporeal light sources.

This light, focused via the proximal plug, is coupled into the endoscope. Recently, the first light-emitting diode (LED)-based light sources have also become available for endoscopic applications.

The quality of any illumination must be comparable to sunlight. One criterion is the color temperature of a light source, which is based on quantum-mechanical considerations on the radiation of ideal, black bodies. The color temperature of the sun is the same as its surface temperature of approximately 6500 K. A further measured variable is the color rendering index, which is a measure of the quality of the color reproduction.

Light sources based on xenon high-pressure short-arc lamps are now the standard light sources for endoscopy, both in the field of flexible endoscopy and in minimally invasive surgery. These systems are characterized by a very homogeneous white light spectrum and high light intensity. Due to the excellent focusing possibilities, xenon light systems can be used just as efficiently in large- and small-caliber endoscopes. The color temperature comes very close to that of daylight; the color rendering index is excellent. Systems with 180 W are now sufficient for almost all endoscopic applications. The light is guided from the light source over an orderless glass fiber bundle (light cable) to the endoscope by means of total reflection in the glass fiber.

With technical advances in the field of LEDs, the first super-bright semiconductor elements are now available, which can also be used in endoscopic illumination. The advantage of this technology lies in the considerably longer lifetime of the illuminant, the high efficiency factor (i. e., less heat generated), and the small dimensions. This means that, alongside self-contained light sources, LEDs can also be installed distally and proximally in endoscopes. The current disadvantage of this lies in the inhomogeneous white light spectrum and the poor focusability of LEDs in small cross-sections of glass fibers.

19.2.2 Imaging: Endoscopes and Image Sensors

Today, endoscopic image transmission is performed optically, fiber-optically or optoelectronically depending on the type of endoscope. The common element in all endoscopes is a distal objective, which determines the direction of view and the image field.

The image field of an endoscope or the numerical aperture (NA) of the endoscope objective is dependent on the refraction index of the ambient medium. If an examination, for example, a cystoscopy, is performed in an aqueous medium, for the same optical conditions, the image field is smaller than in applications in air or in CO_2, as is the case in laparoscopy.

Rigid Endoscopes

In traditional rigid endoscopes, images are transmitted completely optically via a lens system. In this field, the so-called rod lens system of Hopkins has managed to win widespread recognition because of its outstanding quality. Transmission systems based on rod-shaped gradient lenses have failed to gain ground. Alongside rigid endoscopes with fixed, standard directions of view at 0°, 12°, 30°, 45°, 70°, 90°, and 120°, rigid endoscopes have recently been introduced which feature adjustable directions of view [19.8]. This has the advantage of being able to adjust the direction of view during an intervention without changing the external contours of the endoscope.

Image Transmission with Glass Fiber Bundles

Image transmission over ordered optical fiber bundles occurs primarily in *flexible endoscopes*. Today we differentiate between so-called fully flexible image waveguides and semiflexible image waveguides. While semiflexible image waveguides are predominantly used in semiflexible mini-endoscopes and micro-endoscopes (Fig. 19.1) due to their small-caliber variants of approximately 1 mm (35 000 pixels) or less, traditional flexible fiber endoscopes with flexible image waveguides are increasingly being replaced by optoelectronic endoscopes.

Electronic Image Sensors

Miniature charge-coupled device (CCD) and also complementary metal–oxide–semiconductor (CMOS) image sensors are integrated in the tip of the endoscopes with an objective lens and signal processing technology, delivering electronic images with resolutions many times that of fiber endoscopes. In gastroenterologi-

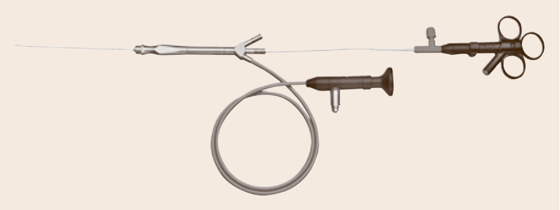

Fig. 19.1 Marchal miniature endoscope sialendoscope (Source: Karl Storz)

cal applications, almost all traditional fiber endoscopes have already been replaced with videoendoscopes.

Video Technology

The first flexible videoendoscopes over 20 years ago featured black-and-white image sensors; the hollow organ was illuminated with sequential red–green–blue (RGB) light, and the compilation of the three color separations was used to calculate and visualize an endoscopic color image continually by means of image conversion. Modern videoendoscopes have color CCD and/or CMOS image sensors with on-chip RGB color filters or color filters for complementary colors (Fig. 19.2).

Video technology is an elementary component of endoscopy. This is not just applicable to the field of flexible videoendoscopes (Fig. 19.3), for which miniaturized image sensors are primarily installed distally, but also to rigid endoscopes, and particularly in the applications of minimally invasive surgery. The use of high-quality, proximal camera systems makes it possible to reproduce the extremely high transmission quality of Hopkins rod lens systems almost perfectly.

Endocameras: 1-Chip and 3-Chip

Proximal endocameras are equipped with one or three image sensors and usually have parfocal zoom objectives (Fig. 19.4). Color rendering is considerably better in 3-chip cameras than in 1-chip systems.

While 1-chip and 3-chip camera systems in standard phase alternating line (PAL) or National Television System Committee (NTSC) standard versions did not come close to the resolution limits of rod lens telescopes, these limits are almost being reached by the latest 3-chip HD endocameras. Alongside the HD endocamera, the remaining components of the transmission elements such as the control unit, monitors, and digital recorders have also been adapted to the high-resolution standard. There is thus no technical reason standing in the way of HD camera systems penetrating the market. The HD requirements are specified by television. There are transmission standards with 1280 × 720 p (progressive) and 1920 × 1080 i (interlaced). The progressive standards (1280 × 720 p/1920 × 1080 p) only are applied to cameras or monitors. Modern HD image sensors with CCD and CMOS technology satisfy these standards.

Stereoendoscopes

Although the image quality of today's endoscopic systems is extraordinarily high, particularly when performing endoscope-assisted MIS interventions surgeons sometimes miss the depth perception offered

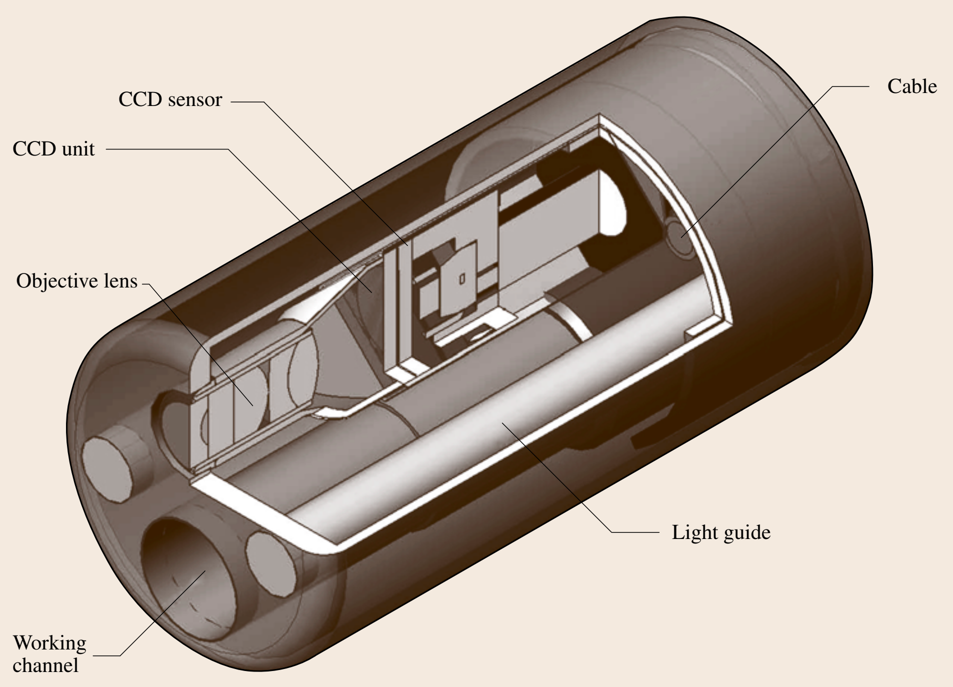

Fig. 19.2 Distal construction of a videoendoscope with miniaturized electronic image sensor (Source: Karl Storz)

Fig. 19.3 Videocystoscope with distal electronic image sensor

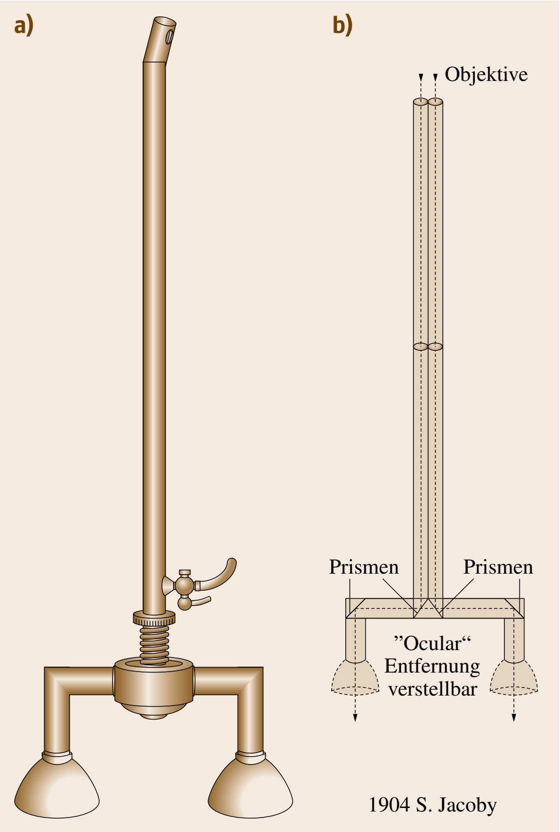

Fig. 19.5a,b Jacoby stereocystoscope (1904) (Source: Reuter, Endoscopy) (drawing adapted)

by their visual system in open operations. There was thus the desire from very early on – as with stereomicroscopy – for stereoendoscopes.

Stereoendoscopes compile endoscopic image information from two different spatial directions – similar to the human eyes. This stereo image pair is delivered to the eyes of the beholder separately via special visualization units.

The first patent for a stereoendoscope was awarded in 1905 [19.9] and was built jointly by Berlin urologist S. Jacoby (Germany), a student of Max Nitze, and the Berlin company Louis & Heinrich Loewenstein in 1904 (Fig. 19.5). It was not until the mid 1990s that a number of manufacturers introduced stereovideoendoscope systems for minimally invasive surgery onto the market. None of these systems proved successful. Studies showed that three-dimensional vision was possible

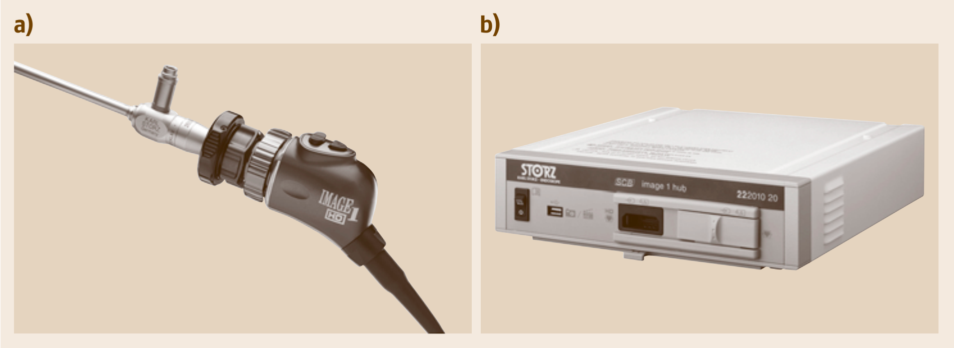

Fig. 19.4a,b High-resolution 3-chip endocamera IMAGE1 HD (**a**) endoscope and 3-chip CCD camera head (**b**) camera control unit (CCU)

over the monitor, but the associated disadvantages such as lower resolution, lower color rendering, less image transparency, and less light meant that operations could not be performed any more efficiently.

Even autostereoscopy systems were offered which did not have any real three-dimensional (3-D) information. Improvements in visualization of 3-D information in particular are necessary for stereoendoscopy to achieve acceptance. One approach is to make the image not only visible from two perspectives, but also to visualize it volumetrically using different focus levels [19.10].

19.2.3 Video Chain

Having dealt with the fundamental components of the light source, light cable, endoscope, and electronic image converter, the following will introduce the term *video chain*. As in every chain, it is important that all links are strong and of high quality, as the overall result of a good endoscopic image is determined by the weakest link in this chain.

It is often the *small* things which can bring a high-quality system to its knees. It is thus particularly important to pay attention to all coupling and connection points, for example, as regards cleanliness of optical surfaces. In the same way, electrical connections and signal cables must be checked carefully for kinks or damaged connections which can affect the result. When choosing a video signal, the highest available quality should be selected.

In the video chain, the endoscopic camera (image converter) is followed by the monitor and optionally the image and video documentation system or telemedicine possibilities.

19.2.4 Monitors

Today, thin-film transistor (TFT) monitors are used almost exclusively in the visualization of endoscopic images. Their quality has increased considerably in recent years. The change in the operating theater away from cathode-ray tube (CRT) monitors towards flat-screen monitors around 2005 occurred at a time when the image reproduction of flat-screen monitors was still considerably below the possibilities offered by CRT monitors. The aura of the new, the expectation that this deficit would be resolved, and the weight advantage, which allows easy and flexible positioning of the screen, paved the way for this premature technological change.

Important criteria when selecting a good monitor are excellent color rendering, as large as possible a viewing angle, and very low latency, i. e., no delay between the operator's actions and visualization thereof on the monitor. In particular the latter point represents an important difference in comparison with monitors for nonmedical applications. In contrast to monitors for other imaging modalities, in endoscopy excellent color resolution is decisive – particularly with respect to the color tones of human tissue. Technical specifications are good for an initial comparison, but true performance and differences between units only become visible in a direct comparison in the operating theater.

19.2.5 Image and Video Documentation

In the beginnings of endoscopy, image documentation was an almost secretive art, as only the examiner was in a position to view the examination field. However, the wish to share this view with fellow examiners was expressed from early on.

Today, the doctor is obliged to document pathological findings and the properly performed operation in image or digital video form. The commonplace, high-quality, electronic image sensors available today make excellent image documentation possible. Of course, an important factor when recording images is that there is optimal visibility and that the site is well irrigated.

Digital archiving of still images is standard today. Because, in general, an electrical connection exists between the recording unit and the image sensor and thus at least indirectly with the patient, the documentation unit must be designed as a medical device. Conventional consumer products are not permitted.

Additionally, systems tailored especially to medical applications allow the doctor to record images systematically and specifically for the intervention being performed and then to prepare these in the corresponding surgical reports. The units must be simple to handle, and in particular, images must be simple to capture [19.11]. There are a number of different systems on the market, which in some cases are tailored to very specific medical applications (Fig. 19.6).

Alongside the capture of still images, documentation of video sequences is playing an increasingly important role. With the increased requirements vis-à-vis resolution, video sequences in HD format (720 p, 16:9) in MPEG2 can achieve data rates of approximately 12 Mbit/s or memory requirements of 90 MB/min. For 1080 p, approximately 20 GB is required per hour of recording time.

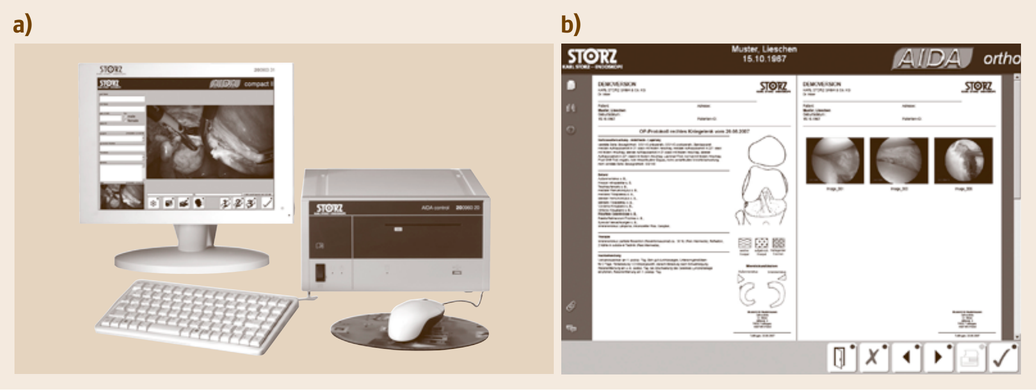

Fig. 19.6a,b Clinically approved system for digital storage of patient, image, and video data. This model is tailored to orthopedic applications: **(a)** AIDA compact ortho, **(b)** documentation mask for the surgical protocol of partial resection of a medial meniscus

The integration of patient-related (image) data in existing hospital information systems (HIS) and picture archiving and communication systems (PACS) is becoming ever more important and should be delivered by high-quality endoscopic image and video memory systems (Sect. 19.3).

19.2.6 Telemedicine in Endoscopy

Broadband data links now allow us to transmit endoscopic video images to any location. This can be in order to get a second opinion or for teaching purposes; it could be to a location within the same hospital or even another continent. The possibility to interact with the recipient is important, either simply via speech or even additionally via graphic interfaces (telestration). For telemedical applications in endoscopy, it is very important that image transmission be temporally synchronized.

19.2.7 Endoscopic Instruments

Alongside the endoscope, which takes care of optical imaging, endoscopy requires a range of further instruments for insertion and manipulation.

Access Instruments

Flexible endoscopes are generally used without further insertion aids. If required, a lubricant may be applied and/or local anesthetic administered. This applies to gastroscopes, colonoscopes, cystoscopes, nasopharyngoscopes, bronchoscopes, etc. These flexible endoscopes are inserted under visual control.

Rigid endoscopes are usually inserted via an insertion tube, which is referred to differently depending on the application. Rigid endoscopes are usually inserted under local or general anesthetic.

To examine the bladder in urology, a single *shaft* is required for a diagnostic procedure and a double shaft system for a surgical intervention, whereby the continuous irrigation provides clear visibility and removes resected tissue or liquid clouded by blood.

In laparoscopy, access to the abdominal cavity (peritoneum) is achieved using a Veress-needle. This step allows, once the peritoneum has been insufflated with gas (CO_2), the creation of a working space without visual control. A rigid endoscope is then introduced via the trocar which is equipped with a sharp trocar mandrel. Additional instruments can then be introduced into the operating region via other trocars under visual control.

Manipulation Instruments

Depending on the application, endoscopy allows the use of a wide variety of instruments which can be used to manipulate tissue, such as exploratory probes, grasping forceps, dissectors, retractors, scissors, hooks, suction and irrigation catheters, resection loops, needle holders, staplers, and clip applicators. Figure 19.7 shows examples of different grasping forceps and a complete set for laparoscopic partial nephrectomy. The range of different instruments is enormous; the leading manufacturers offer several thousand different instruments for the most diverse medical indications.

Dimensions of Minimally Invasive Instruments

The dimensions of the instruments are once again subject to two parameters: As minimally invasive as

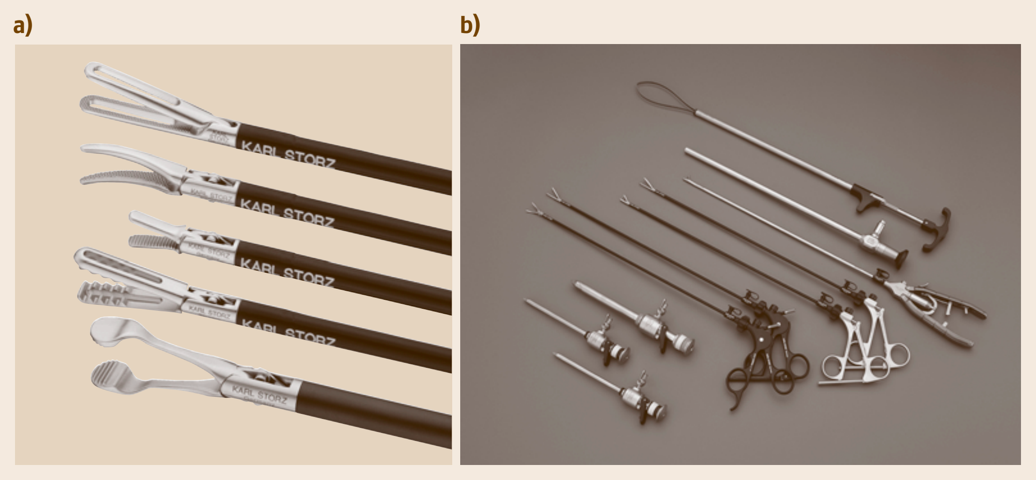

Fig. 19.7a,b Laparoscopic grasping forceps. **(a)** A selection of different jaws, and **(b)** an endoscopic set for laparoscopic partial nephrectomy

possible, and as effective as possible as far as optical image and mechanical manipulation are concerned. For this reason, purely diagnostic instruments are generally more slender and are used without or only under local anesthetic; surgical treatment endoscopes are usually larger in diameter and normally require general anesthetic. The typical diameter of minimally invasive instruments ranges from 10 to 5 mm, which can be seen as standard in laparoscopy, through to 1.9–3.5 mm for minilaparoscopy instruments. Minilaparoscopy is a rediscovered method originally used in internal medicine for liver diagnosis. The approach was first elected by the internists Georg Kelling, Heinrich-Otto Kalk, and John C. Ruddock at the beginning of the 20th century.

Instruments which are introduced into the working channels of flexible endoscopes generally have a diameter ranging from 2.2 to less than 0.5 mm.

19.2.8 Preparation of Endoscopes and Instruments

The significance of hygiene and proper instrument processing has been becoming ever more important in recent years, particularly due to new versions of pathogens which are not sufficiently deactivated by the traditional and often manually performed methods of instrument decontamination and thus potentially pose a hidden risk of human-to-human transferral of infectious microorganisms via surgical instruments. A further reason for this is the ever smaller and more complex nature of instruments, which accordingly places higher requirements as regards the creation of a hygienically sterile state. In principle, all instruments contaminated with microorganisms, particularly invasively and minimally invasively employed instruments, can cause infections. It is thus essential that they be subjected to a safe, validated reprocessing before being reused [19.12].

The reprocessing cycle usually consists of the following steps:

- Cleaning, defined by bioburden reduction by 1–4 log levels (bioburden reduction to 10^{-1}–10^{-4} of initial contamination).
- Disinfection with bacteria reduction to 10^{-4}–10^{-5}.
- Or high level disinfection (bacteria reduction to 10^{-6}), if appropriate for the procedure and surgical instrumentation.
- Sterilization with bacteria reduction to 10^{-6} (killing 99.9999% of bacteria or leaving just one out of one million alive).
- Sterilization process with a double safety factor (so-called *overkill* processes with bacteria reduction to 10^{-12}) which destroys all forms of microbial life.

Cleaning

Cleaning is primarily the mechanical depletion of contaminations, for example, by brushing the surfaces, rinsing, and/or auxiliary use of ultrasound. The effectiveness can be boosted through the use of chemical agents based on enzymes, aldehydes, and other active agents. Thorough cleaning is essential before (high level) desinfection and sterilization because inorganic and organic materials that remain on the surfaces of the instruments can interfere with the effectiveness of these processes.

Disinfection

Disinfection is based either on the use of chemical substances with the corresponding spectrum of activity or on the action principle of the thermal denaturing of organic compounds with the help of water at a temperature of 93 °C or higher, which fully coats the surface of the instrument.

In the meanwhile it has become commonplace to perform these procedures in automated washer–disinfector machines, whereby the parameters relevant for success, such as the concentration of the chemicals, their exposure times, and the temperature, are controlled and monitored accordingly. This avoids the possibility of human error. The reduced handling of contaminated instruments and aggressive chemicals thanks to such fully automated processes also helps to protect staff.

High Level Disinfection. High level disinfection (HLD) is a process that eliminates all pathogenic microorganisms, with the exceptoon of bacterial spores. HLD is normally accomplished using a chemical disinfectant solution.

Sterilization

Following properly performed cleaning and disinfection, the instrument is subjected to sterilization depending on the application at hand. The internationally preferred procedure, in health care facilities due to sterility assurance and cost efficiency, remains steam sterilization (autoclaving) with moist heat (pressurized saturated steam) at a temperature of 134–137 °C (272–279 °F) for an exposure time of 3–5 min, which is subject to different regulations in each country (in the USA, AAMI ST 79) [19.13].

For instruments declared as thermolabile (based on the materials used) there are a number of alternative, low-temperature sterilization processes available such as traditional gas sterilization with ethylene oxide or formaldehyde. Additionally, there are also newer processes available which are based on hydrogen peroxide (H_2O_2), peracetic acid or ozone, which must be assessed and selected for the individual goods to be sterilized in terms of their efficiency, suitability, and material compatibility.

Care

An additional, important aspect in the scope of the reprocessing process of a medical device is service and care, which are usually performed as part of the functional check after successful cleaning/disinfection but before sterilization, and which serve to ensure the functioning and value retention, particularly for instruments with moveable parts. In this step, the moving parts are oiled locally with a silicone-free instrument oil which is biologically harmless (biocompatible) and does not hinder the selected sterilization process (e.g., steam penetration through the care agent film to the surface beneath). The instrument is operated several times to ensure distribution of the care agent within the joint.

Structural Design

Reprocessing of medical devices is a complex process, the success of which is dependent on multiple factors including, importantly, the instrument itself and its mechanical design layout and also the selection of the materials used.

Requirements and Directives

On the topic of hygiene, the legal and regulatory parameters require qualified processes and staff who are suitably trained and qualified.

Cleaning [19.14], disinfection, and sterilization [19.15, 16] are subject to a multitude of field-specific recommendations [19.17], international standards, and national regulations and represent a continuous challenge for both users and manufacturers of medical devices.

19.2.9 Peripheral Units

Alongside the units for videoendoscopic image capture and documentation, a whole range of additional units for assisting surgery are required.

Insufflators and Suction/Irrigation Systems

All MIS interventions performed in the abdomen require the creation of a pneumoperitoneum, which allows organs and tissues to separate slightly and become visually and instrumentally accessible while the abdominal wall remains closed. Gas insufflators are used for the generation and maintenance of the pneumoperitoneum. The regular changing of instruments and suction, e.g., of liquids, result in continuous pressure and volume losses, which place great demands on modern gas insufflation units. The units should provide a maximum flow rate of 30 l/min and not exceed an intra-abdominal pressure of 15 mmHg. To avoid hypothermia in patients undergoing longer interventions, the new generation of units have an integrated module for warming and/or moistening the gas.

Alongside the insufflation of gases it is often necessary in MIS interventions to irrigate the operating site or the lens with liquid or remove blood and tissue remnants. In addition, efficient irrigation can also be used for hydrodissection, i. e., to dissolve adhesions. Modern suction and irrigation systems unite both requirements.

Energy Application Systems

A therapeutic effect is achieved by applying energy in order to cut, separate, initiate hemostasis, coagulate, disintegrate calculi, and for many other actions.

High Frequency

Amongst other things, high-frequency (HF) current (Chap. 34) is used to create thermal effects endoscopically (Fig. 19.8). This can be used to dissect soft tissue and coagulate existing hemorrhaging under endoscopic visual control. There is a general differentiation between monopolar and bipolar HF electrosurgery. Monopolar technology is used most often in endoscopy.

Laser

Lasers have been used in medicine since shortly after their technical implementation at the beginning of the 1960s. Different media allow different laser wavelengths in the visible, infrared, and ultraviolet ranges of the spectrum. Depending on the wavelength, pulse duration, and interaction duration, it is possible to achieve a truly characteristic interaction in the tissue [19.18]. Important interaction partners are water and hemoglobin, the absorption properties of which define how deeply the light penetrates (Chap. 29). Lasers are used widely in ENT [19.19] and urology [19.20], where they are employed for lithotripsy, for tumor coagulation, to separate stenoses, and for prostate enucleation.

Laser light is transmitted in endoscopy via flexible, thin glass fibers; for special applications in the far infrared, mirror systems (CO_2 lasers) are also used. Recent years have seen these systems become ever more compact and also very service-friendly thanks to the use of laser diodes.

Other Energy Delivering Systems

With photodynamic therapy (PDT) an endoscopic tumor treatment is possible which exploits the interaction of (laser) light, oxygen, and a photosensitizer that accumulates selectively in malignant tissue [19.21].

Energy can also be withdrawn endoscopically using *cryoprobes* to destroy tumor tissue by localized supercooling, or be delivered in concentrated form using *ultrasound* to separate tissue.

Systems for Further Interventional Procedures

As endoscopy is very multifaceted, special interventional systems are used for the most diverse of applications. These include

- implants such as endoluminal stents or occluders, which can be introduced endoscopically,
- motorized instruments used to ablate bone and hard tissue (shavers, drills) or to cut soft tissue (morcellators).

19.2.10 Endoscopy Workstations

Endoscopy workstations are tailored to the requirements of the respective application.

Fig. 19.8 High-frequency units (monopolar/bipolar) with an endoscopic instrument set for transurethral resection (TUR)

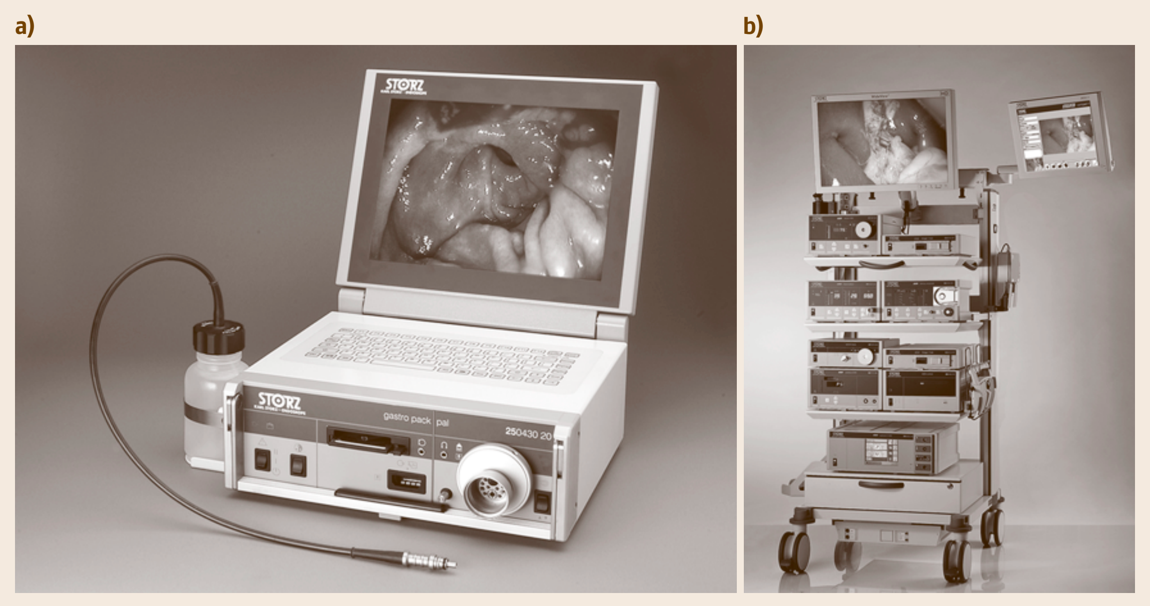

Fig. 19.9a,b Two different endoscopy workstations: **(a)** compact system for outpatient departments with camera control unit, light source, monitor, keyboard, and suction/irrigation pump (Gastropack), **(b)** equipment trolley for the operating theater additionally with HF surgery system, insufflator, and still image and video archiving system

For clinical outpatient departments, emergency medicine, and even doctors' practices specializing in endoscopy, the focus is on a compact system which is fundamentally concentrated on illumination and image rendering. Biopsies and minor interventions are possible. These systems are light and easy to transport, and have been available on the market for quite some time (Fig. 19.9a).

Day clinics, which usually perform routine operations endoscopically and under general anesthetic, and fully equipped operating theaters in hospitals require a larger range of treatment options. As a result, a modular concept is called for, exactly calibrated to the needs at hand. The components are installed on a mobile equipment trolley and can be positioned at the required location in the operating theater. Mobility over greater distances is also possible to some extent (Fig. 19.9b).

Newly designed operating theaters are now predominantly equipped with fully integrated workstations (Sect. 19.3).

19.3 Integrated Operating Theaters

As a result of the rapid development in minimally invasive surgery, there is now a wide variety of devices in the operating theater in comparison with the past. The operation and handling of these systems, which are often from different manufacturers, have thus become more and more complex and time consuming. In addition, the surgeon requires a considerable amount of time to document all the points relevant to surgery and compile a report. On top of all this, the surgeon is continuously being confronted with more complex MIS interventions, and time budgets are always being cut. These increasing requirements can only be satisfied by improving the ergonomic handling of units and instruments and comprehensive computer-assisted documentation and data provision [19.22]. The design of system workstations and new concepts for integrated operating theaters set benchmarks for the logistical harmonization of operating activities, reduce stress for the surgeon and assistants, and thus reduce operating and changeover times.

System integration allows, amongst other things, central control and operation of endoscopy units and further devices capable of being integrated such as HF units, operating tables, operating lamps, and operating light cameras, as well as documentation systems and the telemedicine unit via a central touch-sensitive monitor (touchscreen) directly from the sterile area and/or at the nurse's workstation [19.23]. There is also the possibility to preset start configurations for the system parameters and telemedicine basic settings with personal or intervention-specific presettings, so that the units set themselves automatically when the respective configuration is selected. This saves time on the one hand and contributes to quality assurance on the other. The user interfaces of the integrated devices are represented one-to-one on the system's user interface. Users thus do not have to familiarize themselves with a new concept. Alongside the realistic user interface for each individual unit there is also a freely definable overview display of the most important unit parameters. The individual, selected units can also be controlled from this display mode. In addition, the visualization of unit parameters as well as alarm and status messages from the operating system is realized in a section of the touchscreen clearly visible to the surgeon.

A further dimension of operating room (OR) integration is data management, which results from the obligatory documentation requirement. In this respect, the systems offer all necessary functions for holistic, accurate documentation of all endoscopic and open interventions. User-friendly entry systems allow the simple capture of still images, video sequences, and spoken commentaries on findings and operative interventions directly from the sterile area by simply activating the touchscreen, a footswitch or the camera head buttons.

A digital imaging and communications in medicine (DICOM) interface can be used to give the system access to DICOM worklists available on the hospital network, which allows rapid transfer of patient data.

Alongside system integration and data management, audio and video technology for communication and data transfer also form part of the holistic concept of an optimally integrated operating solution. The different video signals from endoscopic and room cameras as well as from the PACS and HIS systems can also in principle be connected and routed as required and even telecommunicated, thus allowing them to be displayed outside of the operating theater. Audio and video technologies are also controlled via the touchscreen at the nurse's workstation. The man–machine standard interfaces often already feature intelligent voice-controlled systems.

The focus on integrated OR systems (Fig. 19.10), which is increasing productivity and efficiency in many surgical procedures, has put hospital administration in

Fig. 19.10 Fully integrated operating room OR1 Karl Storz (Source: Karl Storz)

a position to see the operating theater as an important source of income. In terms of profitability, the operating theater has become a decisive factor in the success of a hospital.

These integration technologies have been recently complemented by efficient OR management systems. Efficient OR management is based on the harmonization of all processes and integrated components combined with the possibility to connect seamlessly with the hospital information system. Such a system (e.g., Orchestrion [19.24]) makes it possible to optimize the planning of operations and staff schedules, and ensures efficient flow of information between the operating theaters and the hospital information system. By optimizing the way in which the operating theater is used, the hospital achieves smoother processes and is thus in the position to offer patients a higher quality of treatment. This tool is helpful in preplanning of operations and coordinates and controls the use of available OR resources. It is thus an important element in the development of strategies for optimal utilization of limited resources. Thanks to the implementation of standardized interfaces, these tools can be easily integrated into the existing information technology (IT) structures of a hospital. The modular design of the system can be adapted to suit the individual requirements of every hospital and offers a dynamic platform to be able to integrate future developments and improvements.

19.4 Medical Applications

Endoscopy is employed in a wide variety of medical and surgical disciplines for diagnosis and treatment. It is routinely used in, amongst others, the different subdisciplines of ear–nose–throat medicine, pneumology, gastroenterology, abdominal surgery, urology, gynecology, and also sports medicine.

Users are found in all strata of the healthcare system, from specialists to ambulatory healthcare centers and day clinics as well as all types of hospitals from primary health care to university hospitals.

19.4.1 Most Common Procedures

The most common surgical endoscopic interventions are arthroscopic interventions, endoscopic sinus surgery, laparoscopic gallbladder removal, transurethral resection of bladder tumors, and benign prostate tissue (BPH) [19.25]. Hernias, bariatric surgery hysterectomy, and appendectomy are some of the most common surgical procedures, although they are only partially performed endoscopically. Additionally, in 2008, more than 16 million diagnostic endoscopic examinations were performed in the US.

19.4.2 Special Procedures

The following illustrates some special endoscopic applications to demonstrate the potential and particular possibilities, but by no means does it claim to be exhaustive.

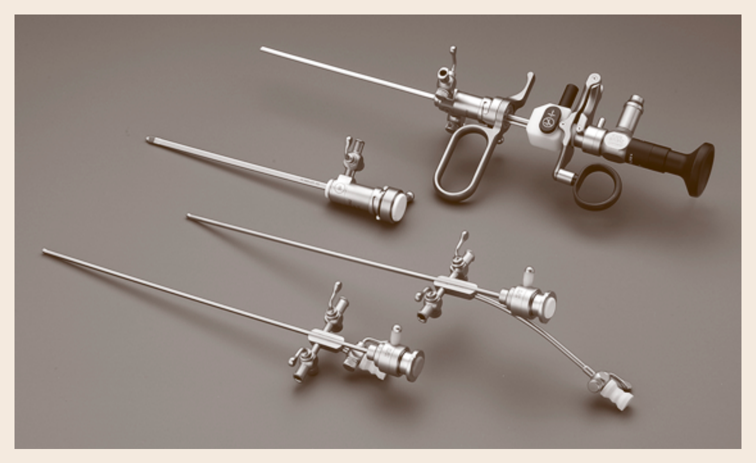

Fig. 19.11 Miniaturization in endoscopy using pediatric urology as an example. *Top*: resectoscope for tissue ablation with HF current, shaft diameter 3.7 mm; *bottom*: cystoscope shafts (Source: Karl Storz)

Fig. 19.12 Spinal system for treatment of disc herniations and spinal canal stenoses (Source: Karl Storz)

19.4.3 Miniaturization

Endoscopes can be miniaturized so that they are suitable for operations on children and newborns. To give an example, we cite the incision of the closed ureteral orifices in a newborn baby with hydronephrosis, whereby a small scalpel is introduced via a delicate pediatric cystoscope and used to remove an anatomical anomaly (Fig. 19.11). Today it is even possible to operate endoscopically on the fetus while it is still in the womb. Other applications for mini-endoscopy include examination of the tear duct in the eye, salivary ducts in the mouth (Fig. 19.1), lactiferous ducts in the breast or the fallopian tubes. This is where the finest, flexible fiber-optic endoscopes with diameters of 0.3 mm to approximately 1 mm come into use.

19.4.4 Controlled Access

In some medical applications it was previously not possible or usual to work under visual control. In terms of more minimally invasive and safer accesses, endoscopic assistance has become established in anesthesia and emergency medicine in recent years in attempts to find the right access in cases of difficult intubation.

Endoscopic examination of the uterus (hysteroscopy) is also on the advance in this respect, particularly for performing targeted biopsies or removal of polyps, in comparison with blind curettage. This is driven by improved reimbursement and new indications such as transcervical sterilization. Even if hysteroscopy could be used without causing pain and without anesthesia by any specialist in a practice, enhanced training and logistics is needed to support this procedure in an office environment.

19.4.5 Alternatives to Surgical Microscopes

In the fields where surgical microscopes are used, endoscopic procedures are gaining ground. Endoscopic procedures are becoming increasingly popular in laryngeal surgery, neurosurgery, and in delicate operations in spinal surgery (Fig. 19.12). The depth of field of endoscopic systems is considerably larger than with microscopes. Moreover, endoscopes can be used to look around corners, which is not possible with microscopes as a result of the large working distance.

19.4.6 Gastroenterological Endoscopy

Possibilities to examine the digestive tract are offered by a wide range of extremely differentiated endoscopy systems which can be coupled with ultrasound, zoom or fluorescence procedures. In addition, a piggyback procedure is used for examination of the bile ducts, in which a small-caliber endoscope is introduced through a large-caliber duodenoscope. Gastroscopy and colonosopy are amongst the most commonly employed diagnostic procedures. Fig. 19.13 shows a typical, flexible endoscope from gastroenterology with a distal image sensor.

19.5 Tissue Differentiation

As discussed in Sect. 19.1.2, illumination is modulated by the illuminated tissue and perceived by an image sensor. A variety of procedures now make it possible to gather information about the tissue, being considerably more detailed than the information offered by the colored white-light image.

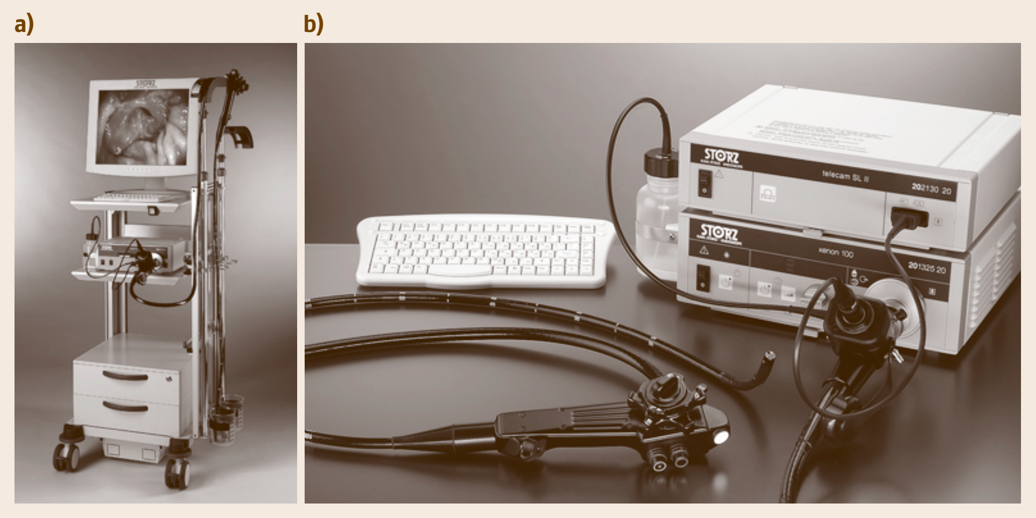

Fig. 19.13a,b Flexible videocolonoscope with distal, high-resolution solid-state image sensor: **(a)** video cart, **(b)** close up look of videocolonoscope, CCU and lightsource

19.5.1 Molecular Imaging/ Fluorescence Endoscopy

Molecular imaging is one of the great beacons of hope in the field of cancer research and early detection, as it makes pathological changes visible at the cellular level. Fluorescence-based endoscopy systems are also of great importance as optical detection units. The procedure itself uses the distinct metabolism of abnormal cells to display fluorescent substances accumulated in the tumor via a molecular mechanism. This optical form of molecular imaging, in which the suspicious area in the endoscopic image lights up in color, was initially used in bladder cancer with great success [19.26].

Carcinomata in situ with a thickness of just a few micrometers ($< 30\,\mu m$) can be visualized with this technique at a very early stage (Fig. 19.14). No other imaging procedure is in a position to do this.

Nowadays, the procedure is also used for numerous other organ systems. The target of various initiatives in molecular imaging is to have new disease-specific marker substances and tailored detection systems available in the future. This can only occur through cooperative alliances between pharmaceutical companies and device manufacturers.

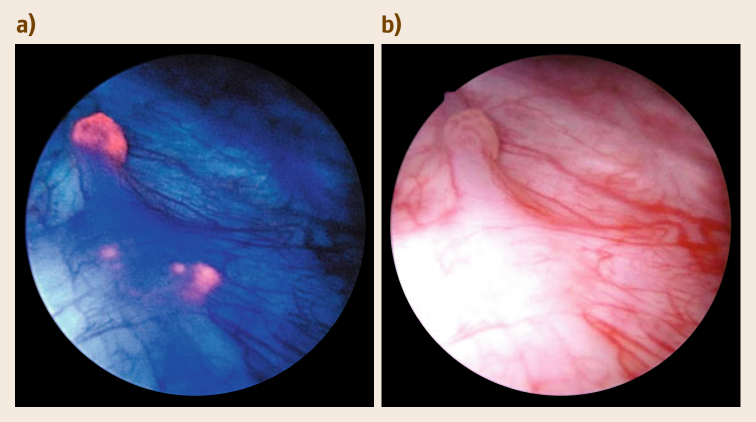

Fig. 19.14a,b Endoscopic cystoscopy of small exophytic tumor with small satellite tumors: **(a)** photodynamic diagnosis (PDD) mode, **(b)** white light (Source: Karl Storz)

19.5.2 Infrared Endoscopy

Infrared endoscopy, i. e., endoscopic representation of image information in the infrared range, has been on the wishlist of diagnostic medicine for many years. For example, it could be used to recognize inflammatory conditions better. However, this target is subject to technological limitations. Endoscopic capture and transmission of near-infrared (NIR) light from 650 nm up to approximately 1000 nm and a maximum of 2000 nm is possible with existing technologies. Image transmission beyond that cannot be achieved with standard optically transparent lenses.

Current research and development activities have thus concentrated on the NIR range. Attempts are being made, amongst other things, to determine perfusion following transplants or visualize enteroanastomotic insufficiencies at an early stage. For intraoperative examination of the anastomosis following intestinal resection, the surgeon has visual and manual control available in open surgery; in laparoscopic interventions, however, only visual, endoscopically assisted control under white light is available. For better control of intestinal perfusion, *Carus* et al. [19.27] first employed intraoperative fluorescence diagnostics for laparoscopic colorectal anastomosis. The basis for these applications is the NIR-transmitting endoscope as well as cameras and optical contrast agents, which are excited by special excitation light to exhibit NIR fluorescence. The intravenously administered marker indocyanine green (ICG) is excited to fluoresce in the infrared region at around 830 nm on exposure to red light. The diagnostic principle has been used since the 1960s to examine the retina, and as a result ICG is approved for the most diverse of applications in many countries. It is hoped that use of ICG fluorescence laparoscopy technology will significantly reduce the relatively high rate of anastomotic insufficiencies in the colon and rectum.

Technically, the ICG fluorescence system is based on an endoscopic 300 W xenon light source, into the light path of which an ICG excitation filter can be swung alternately. As a result of this deep red excitation light, the presence of ICG in blood can be detected as NIR fluorescence even in deeper tissue structures. This fluorescence is detected by an imaging laparoscope via an observation filter, separated from interfering light rays, and converted into an electronic image signal by a special camera which is sensitive to the NIR range. A type of false-color coding is used to convert the infrared (IR) fluorescence information to a visible range and display it on the monitor. Optionally, one can swap between the standard white-light mode and the IR mode.

19.5.3 Zoom Endoscopes, Endomicroscopes

Today, histological microscopic examination is the gold standard for assessing tissue with regard to its nature or malign degeneration. There has long been a desire to be able to perform this laboratory examination in situ at the time of the operation.

As early as 1980, *Hamou* [19.28] described a procedure in Paris in which he dyed the tissue to be examined with methylene blue and then viewed it with a rigid endoscope, which normally delivers a standard wide-angle image or, in contact with tissue and by altering the optical focus level, an endoscopic image with 150× optical magnification. This allowed the recognition of the size of the cell nuclei and anomalies in the cell structure. The procedure was commercialized by Karl Storz under the term contact endoscopy and used in the detection of cervical dysplasia and to examine the larynx. The procedure did not become widely used. Today, magnification endoscopy has found a new impetus in gastroenterology.

The optical magnification of extended tissue structures superimposes the information of many tissue layers on top of each other. Recent years have seen the further development of procedures from microscopy which can be used to produce a defined slice level endoscopically using the confocal principle. To do this, one requires either a distal microscanner or a proximal scanner, which is technically demanding. Alternative procedures are visible on the horizon, but clinical evidence is not yet available.

19.5.4 Ultrasound Endoscopes

Endoscopy is an unrivalled procedure for assessing the surfaces of organs. Ultrasound technology is used to assess deeper structures and processes. Endoscope-assisted ultrasound examinations allow tissue characterization and conclusions about deeper layers, which remain invisible in purely endoscopic observation. Piezoceramic ultrasound elements are integrated either as individual elements or in the form of an array into the tip of the endoscope and emit short, high-frequency ultrasound pulses into the tissue. These sonic pulses are reflected by tissue interfaces and other tissue inhomogeneities at different penetration depths, captured by the same ultrasound element again, converted into electrical signals, and transmitted to an evaluating processor unit. The information from various ultrasound echograms is compiled to create so-called ultrasound B-mode images (brightness images) and visualized for the doctor for further evaluation on the monitor. The frequencies of endosonographic systems are currently in the range 5–30 MHz. Earlier electromechanical scanner units have now been exclusively replaced by electronically controlled array transducers (linear/radial scanners). Interventional operations in particular, e.g., fine-needle biopsies, can be performed under endosonographic control.

19.5.5 Optical Coherence Tomography

Optical coherence tomography (OCT) can be seen as an optical equivalent to ultrasound imaging. The basic principle of OCT is based on white-light interferometry. In this, an arm with known optical path length is used as a reference to the measuring arm. The interference of the signals from the two arms provides a pattern, which one can use to determine the relative optical path lengths within a depth profile. In a one-dimensional raster scan, the ray is then directed transversally in one or two directions, which allows one to record a two-dimensional (2-D) or 3-D tomogram.

Today, OCT is routinely used in ophthalmology; in endoscopy, current applications are still experimental (Fig. 19.15), mostly on the larynx and in the bladder. The penetration depth is around 2 mm.

19.5.6 Virtual Chromoendoscopy

Differentiation between benign and malignant structures is an important aspect of endoscopic diagnostics. To improve conclusions with regard to tissue characterization and tissue differentiation, the application of coloring methods with, e.g., methylene blue, toluidine blue, and indigo carmine has been common for many years. Similar contrast accentuations are achieved by the use of acetic acid, for example, in early detection of carcinomata in the cervix, esophagus, and oral cavity.

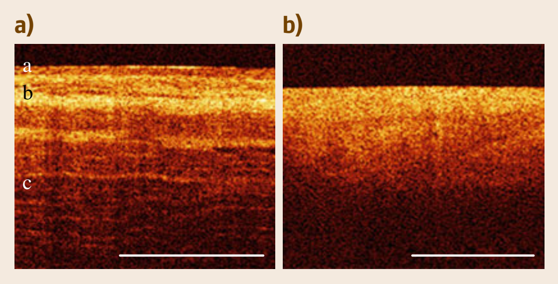

Fig. 19.15 **(a)** Endoscopic OCT images in false-color rendering. Healthy urothelium (*a* urothelium, *b* lamina propria, *c* muscularis propria); **(b)** muscle-invasive lesion, the layer structure is no longer identifiable, scale 1 mm (Source: A. Goh, S.P. Lerner, Baylor College of Medicine, Houston)

Several years ago these technologies were joined by spectral image processing technologies, which can be used to perform special real-time color analyses of videoendoscopic images. We differentiate between purely software-based systems (virtual chromoendoscopy) (Fig. 19.16) and systems which visualize a combination of narrowband illumination with specific, electronic color assignment (narrowband imaging, NBI). The idea behind the spectral processing techniques is to improve the recognizability of special structures by limiting optical image information to a narrowband range in comparison with the whole visible spectral range, thus suppressing less relevant spectral information. For this reason, the wavelengths which are of greatest interest in endoscopic examinations are those which correspond to the range in which the blood pigment hemoglobin displays the highest absorption. These lie in the blue between approximately 410 and 440 nm and in the green between 530 and

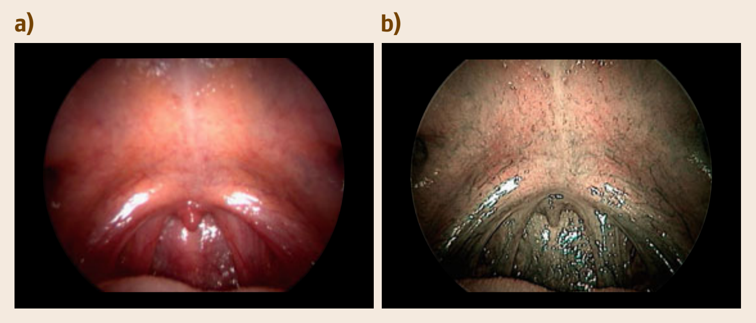

Fig. 19.16a,b Virtual chromoendoscopy: **(a)** white-light image of the palate, **(b)** defined vascular structure (Source: Karl Storz)

580 nm. Restriction to such spectral ranges allows contrast accentuation between tissue regions with higher and lower hemoglobin concentrations. This allows for better differentiation of vascular structures near to the surface. Pathological structures, e.g., in the region of the esophagus, are easier to identify.

19.6 Further Future Developments

Alongside the procedures for tissue characterization (Sect. 19.5) there are a whole host of further innovative approaches. The first clinical implementation has already occurred, but for the most part clinical acceptance cannot yet be foreseen.

19.6.1 Natural Orifice Translumenal Endoscopic Surgery – NOTES

For some years now there have been intense discussions in surgical and gastroenterological circles about further reduction of the trauma associated with the surgical approach. It is starting to look possible to cross the boundaries between internistic gastroenterology and abdominal surgery. To do this, it is accepted that a previously intact organ structure (e.g., the stomach or vagina) will need to be penetrated surgically. In contrast to trauma associated with the surgical approach through the abdominal wall, however, this is seen as acceptable by the protagonists.

Operating via natural orifices appears possible. NOTES stands for natural orifice translumenal endoscopic surgery. The aims were laid down in 2005 in a white paper [19.29] led by *Rattner* and *Kalloo*. To date, amongst other things, gallbladders and appendices have already been removed from patients transgastrically (via the stomach) and transvaginally [19.30] (via the vagina). We can assume that, by the beginning of 2010, over 500 patients have undergone NOTES procedures across the world. A large percentage have been performed on women transvaginally, as this approach has been well known for a long time and the access site can be closed easily in open surgery without any problems. In principle, the transgastric approach is preferred, but no satisfactory method of closing the stomach wall has yet been found. Some of the operations are performed as hybrids with the help of a laparoscopic port.

The very high initial expectations placed on instruments and surgical techniques have still not been met. Nevertheless, some technological innovations have been realized in this regard.

Figure 19.17 shows the ANUBISCOPE from Karl Storz as an example. It is used for transgastric appli-

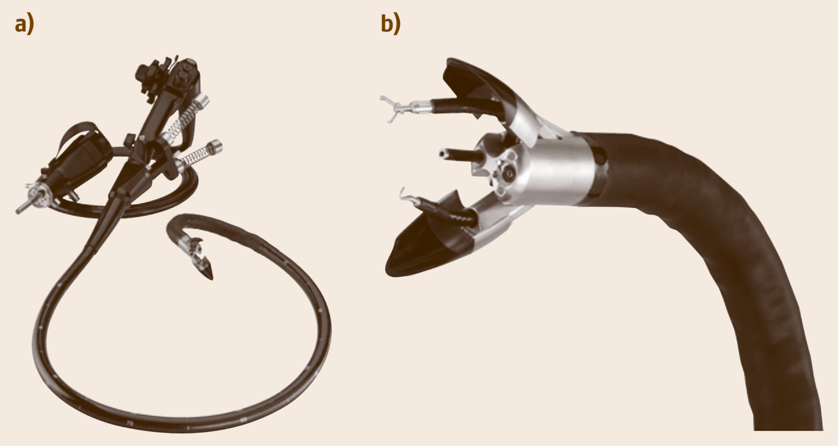

Fig. 19.17a,b Flexible, interventional platform for performing transgastric operations, ANUBISCOPE with three working channels, two of which can be angled for triangulation of flexible working instruments. The two half-shells can be moved: when closed they serve as an atraumatic introduction and dilation aid; when open they act as a retractor and secure the operating region against the nonvisible region. **(a)** Whole system, **(b)** distal close-up with coagulation hook, grasping forceps, and suction catheter (Source: Karl Storz, FDA approval pending)

cations with total reflection option (210° angle in four directions). This is a platform with a flexible shaft; the working channels are larger and intended for flexible instruments, which can be angled and used to manipulate tissue accordingly. Triangulation, which is not possible in traditional, internistic endoscopy, is made possible here by the instruments which can be angled. The special mechanism on the tip of the endoscope allows atraumatic introduction as with a blunt trocar in laparoscopy (closed state), and in the operating area, thanks to the open position of the half-shells, offers protected operating, stabilization of the instruments, and their triangulation. A third working channel can be used to introduce further instruments such as an articulating catheter for suction or as a guide for a laser fiber.

It is still too early to sum up the history of NOTES, as it is far from finished.

19.6.2 Single Port

Once the enormous challenge of NOTES (Sect. 19.6.1) became apparent to physicians and engineers working at companies active in the field, they began to search for alternative innovations. The idea of reducing the trauma associated with the surgical approach and not leaving any scars was expanded on so that work should only be performed via a single laparoscopic site or a single port. As a matter of preference, the umbilicus was suggested as the approach, because this would at least avoid creating a new scar (the umbilicus being, to a certain extent, a natural scar).

A multitude of different terms were developed, which although they might differ slightly in the details, all basically follow the same principle. *Single-port laparoscopic surgery* refers to an approach port which can accommodate several instruments (Fig. 19.18).

Despite its potential advantages, the procedure is associated with considerable ergonomic restrictions and limitations, as it is more difficult to perform laparoscopic interventions via this procedure and it demands extraordinary dexterity and expert knowledge on the part of the surgeon. The Dundee ENDOCONE system was realized as an integral insertion–instrument–retraction system to resolve this problem and facilitate the performance of single-port operations. The system features curved, instruments in order to enlarge the operating space between the surgeon's hands.

19.6.3 Simulation

The establishment of minimally invasive surgery (MIS) brought with it an increase in training requirements for new endoscopic techniques. Hand–eye coordination training with endoscopic instruments using simple in vitro models is not sufficient for basic MIS training. Intensive courses using in vivo large-animal models have been necessary to date in order to teach prospective MIS surgeons the requisite instrumental interactions and manoeuvres. The availability of high-performance

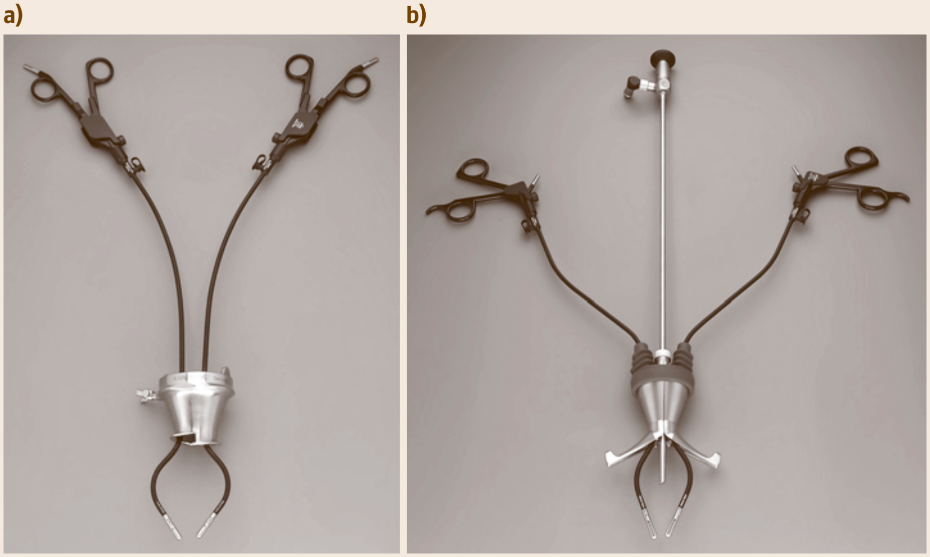

Fig. 19.18a,b Single-port approach systems and instruments display various differences, particularly when it comes to their shape. **(a)** CUSCHIERI ENDOCONE, **(b)** X-CONE consisting of two half-shells, which are locked together via a seal (Source: Karl Storz)

computers and graphic processors means that it is now possible to produce virtual simulators, which on the one hand present the operating site relatively realistically and, on the other hand, can already simulate the interactions between the instruments and the soft tissue almost as in real life. The requirements vis-à-vis real-time performance and image resolution are largely met.

There are different simulators for the different specialities, e.g., urology [19.31], gynecology, visceral surgery, coloscopy, etc. The simulator system for abdominal surgery comprises a monitor, a control unit, a simulation personal computer (PC), a patient torso with trocar modules including tactile force feedback, and endoscopic instruments (Fig. 19.19).

The available training scenarios offer the possibility to practice the individual techniques such as handling of the endoscopic camera, the endoscopic grasping forceps, and a suction/irrigation handle, etc. Combinations can also be trained. The variation of the individual scenarios happens via different difficulty levels and different directions of vision (0°, 30°, 45°) on the one hand, and different laparoscopic views on the other, which are varied within the simulation but are also dependent on the position of the trocar modules, which can be placed in almost any position on the patient module.

The simulators offer an easy-to-use user interface. All possible actions are described within the interface with text or additionally with images, so that the user can start with the system directly. The user can choose between different scenarios, tasks, and difficulty levels. In addition, there is usually also an integrated student–teacher system. Individual students then have the possibility to create user accounts in which the results of the training scenarios are saved. This presents the opportunity of monitoring training progress. Additionally, the teacher can view the results of all the created user accounts via his login.

19.6.4 Endorobotics

Fig. 19.19 Virtual MIS simulator for laparoscopic interventions

Robots are stationary or mobile machines which perform specified tasks according to a defined program. One possible task is the use in medical environments to move or position instruments or visual systems. Problematic, however, in the medical environment, is the autonomous movement of such a system. Today we do not speak of robots, but of handling systems, which operate under direct interactive control of the surgeon. In endoscopy, one currently differentiates between two types of *robot systems*. Firstly, there are so-called telemanipulation systems, which are used to position and activate endoscopic instruments and endoscopes by remote control. Secondly, wireless videocapsules are sometimes referred to as endorobots, as they pass through the gastrointestinal tract as an autonomous endoscopic visualization system, compiling corresponding image information for transmission to the outside (Sect. 19.6.5).

The following describes endoscopic telemanipulation systems [19.32–35]. The first attempts at telemanipulation systems were made by a team led by *Taylor* [19.36]. A positioning system for laparoscopes was launched onto the market in the mid 1990s by Computer Motion, Inc. [19.37]. Speech input was used to guide the endoscope in the abdomen and position it. This system was later superseded by the Da Vinci telemanipulation system from Intuitive Surgical. The Da Vinci system is composed of a control unit with stereo monitor and, on the patient side, a three-armed instrument positioning/activation unit and a positionable stereolaparoscope. During laparoscopic interventions, the surgeon sits at the control console and moves the instruments on the operating table from this position. The software-assisted 3-D visualization provides the doctor with a detailed, 3-D view of the operating field and a great depth of field. The doctor controls the instruments from the control console using control elements. In doing so, the exact movements of his wrist, hand, and fingers are acutely enacted by the remote-controlled instruments. The camera-assisted laparoscope can be moved and positioned in the body; simultaneously, the image section can be magnified. This provides the surgeon with optimal vision over the operating field. The operating and, in particular, the performance of critical manoeuvres are facilitated for the doctor, but due to the high cost of the system and the extensive time and effort needed pre- and postoperatively, the system has only enjoyed success in a single MIS application.

19.6.5 Capsule Endoscopy

The endocapsule contains an image sensor, an illumination unit based on mini LEDs, and usually a localization element which can be used to determine the position of the capsule in the gastrointestinal tract. An external control unit receives the image information and saves it in the form of a series of pictures spanning several hours. In addition to the visualization of the esophagus, this type of wireless endopill diagnostics allows inspection of the entire small intestine in sufficiently good image quality. This new procedure is easy to perform, very patient friendly, and considerably more informative than conventional radiological intestinal contrast agent examinations. Prior to capsule endoscopy, there was no satisfactory way of visualizing the small intestine, be it endoscopically or radiologically. A number of systems are currently available on the market.

However, capsule endoscopy is still not an alternative to videogastroscopy or videocolonoscopy for examining the stomach or colon. This is due to the fact that there is no way of controlling the movement and direction of the pill and that there is no possibility for direct treatment when the respective findings are detected.

Current research activities are thus concentrated on the remote control of endopills [19.38].

19.6.6 Endonavigation

The first steps in researching endonavigation were taken at the end of the 1980s in paranasal sinus surgery [19.39, 40]. The position of endoscopic paranasal sinus surgery instruments was compiled in three dimensions and then visualized in a preoperatively recorded three-dimensional CT data record. Position detection is effected via the instrument tip; the instrument itself was held in a holding arm with six degrees of freedom; the position was then determined by an angle encoder system [19.41]. Further developments at the beginning of the 1990s allowed so-called *noncontact* navigation systems. Camera systems detect the position of instruments based on reflectors mounted on the instruments (Fig. 19.20). Such systems have managed to make a place for themselves in neurosurgery, orthopedic surgery, and paranasal sinus surgery. As optical position detection of the instruments occurs via the extracorporeal portion of the instrument, use of these navigation systems is only possible in combination with rigid instruments and/or endoscopes.

Fig. 19.20 Endonavigation system SURGICAL COCKPIT (Source: Karl Storz)

The use of innovative electromagnetic-based navigation systems has now made it possible to detect the intracorporeal position of (flexible) instruments. This requires the integration of a miniaturized coil element in the instrument. The advantage lies in the possibility of determining the intracorporeal position, i. e., the localization of flexible instruments and endoscopes [19.42]. An associated disadvantage is that ferromagnetic materials around the measurements can lead to measuring errors. In the future, navigation techniques in combination with other sensor technologies will facilitate new endoscopic visualization and documentation techniques [19.43, 44].