Image Systems in Endo-Laparoscopic Surgery

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Introduction

The field of minimally invasive surgery (MIS) has seen tremendous growth and advancement since its advent in the 1980s. New procedures, MIS techniques, and instruments are evolving regularly which makes it important for surgeons to be familiar with these developments. MIS is a technologically dependent specialty and every surgeon is expected to have good background knowledge of new instruments and imaging systems. Endo-laparoscopic surgery is conducted using an array of imaging devices that are all interconnected. Basic components of the image systems in endo-laparoscopy include a telescope connected to a light source and a controller unit. The images are then transmitted through a monitor that allows the surgical team to visualize the operative field. Documentation of the surgical procedure, both real-time and recorded, can be achieved through a video recording hub and/or printer.

Telescope

There are two common types of endoscope: One using standard Rod-lens system and the other is a fully digital scope using a camera chip on the tip of the rigid or flexible endoscope.

The conventional Endoscope is made of surgical stainless steel and contains a series of optical lens comprised of precisely aligned glass lenses and spacers (so-called Rod Lens System). It contains an objective lens, which is located at the distal tip of the rigid endoscope, which determines the viewing angle. The light post at right angles to the shaft allows attachment of the light cable to the telescope. The eyepiece or ocular lens remains outside of the patient's body and is attached to a camera to view the images on a video monitor.

Telescopes or laparoscopes come in various diameters. The 10 mm diameter is the most commonly used scope and provides the greatest light and visual acuity. Other varieties are the 5 mm and 2–3 mm needlescopes which is mostly used in children. Full screen 5 mm laparoscopes capable of providing images comparable to 10 mm systems are now available in the market. Various visualization capabilities such as a 0° forward viewing, 30 or 45° telescope are the varieties (Fig. 1).

Advances in digital endoscopy utilizes a chip on the tip (CMOS or CCD) of a rigid videolaparoscope (e.g., Endoeye Olympus™) or flexible endoscope. There is no longer an interface

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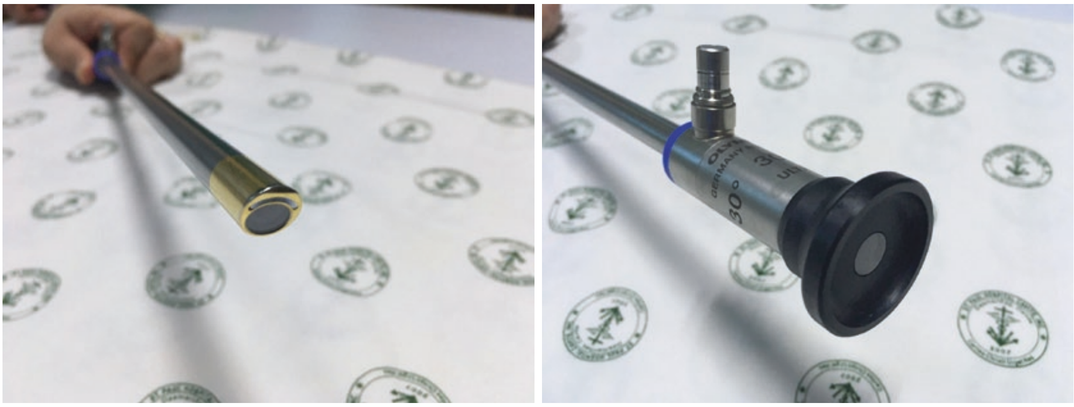

Fig. 1 10 mm forward oblique telescope (30°)

between the camera head and the endoscope, and traditional rod lenses are no longer used. In lieu of this, a distally mounted image sensor with a lens is used. This delivers better resolution and clarity of images. It also offers a focus-free and better ergonomic design. These scopes are also autoclavable.

Light Source

This is critical for visualization of the operative field. A typical light source is composed of a lamp or bulb, a condensing lens, a heat filter, and an intensity-controlled circuit. Light quality is dependent on the type of lamp that is used. Most light sources nowadays use the high-intensity xenon light source which provides white light illumination (Fig. 2). The previous light sources used a quartz halogen bulb, incandescent bulbs, and metal halide vapor arc lamps.

Newer light sources have incorporated the use of LED technology. An LED light source is able to deliver cold, white light that generates virtually no heat. These light sources are energy-efficient and noiseless. Compared to Xenon light sources (Fig. 2), LED light sources offer up to 30,000 h of service life and therefore do not require lamp changes.

Light Cable

Light is transmitted from the lamp to the laparoscope through cables (Fig. 3). The two types of cables are the fiberoptic and the liquid crystal gel cable.

Fig. 2 Xenon light source (Olympus VISERA ELITE™)

Fig. 3 Fiberoptic light cable

The principle of fiberoptic cables is based on the total internal reflection of light wherein light would enter one end of the fiber after numerous internal reflections and go out through the other end with virtually all its strength intact. Fiberoptic cables are flexible but do not transmit a precise light spectrum. They have a very high quality of optical transmission but are fragile.

Liquid crystal gel cable is composed of a sheath that is filled with a clear gel. These cables are capable of transmitting more light than optic fibers. They can transmit a complete spectrum but are more rigid and fragile. Liquid crystal gel cables require soaking for sterilization and cannot be gas sterilized.

Camera Head (From 2D to 3D Technology)

Since the advent of laparoscopy, technologies in camera systems have quickly evolved. A few decades ago, the main technology utilized in minimal access surgery was the charged coupled device. Now, two new systems are at the cutting edge of surgical video technology: 3D and UHD/4 K. These systems were developed with the goal of providing better imaging and better depth perception.

The traditional camera for endo-laparoscopic surgery (Fig. 4) contains a solid-state silicon chip or the charged coupled device (CCD). This essentially functions as an electric retina and consists of an array of light-sensitive silicon elements. Silicon emits an electrical charge when exposed to light. These charges can be amplified, transmitted, displayed, and recorded. Each silicon element contributes one unit (referred to as a pixel) to the total image. The resolution or clarity of the image depends upon the number of pixels or light receptors on the chip. Standard cameras in endo-laparoscopic use contains 250,000–380,000 pixels. The single-chip camera has a composite transmission in which three colors of red, blue, and green are compressed into a single chip. The three-chip camera has a separate chip for each color with a high resolution. The clarity of the image eventually displayed or recorded will also depend on the resolution capability of the monitor and the recording medium. The resolution is defined as the number of vertical lines that can be discriminated as separate in three quarters of the width of the monitor screen. Standard consumer-grade video monitors have 350 lines, monitors with about 700 lines are preferred for laparoscopy.

Three-dimensional (3D) cameras have been developed to overcome the lack of depth perception in traditional 2D laparoscopy. In 3D laparoscopy, different images are presented to each of the surgeon's eyes to facilitate stereopsis. This is accomplished using two different technologies: by a single channel laparoscopes with one system of lenses, then using a digital filter to separate the images for each eye; another system utilizes a dual channel laparoscopes with one lens system for each eye, this provides a real and better stereovision (Fig. 5).

In both technologies, it is necessary for the surgeons and the OR Staff to wear passive or active stereoscopic glasses to visualize the 3D Image (Fig. 6a–c).

The eyepieces which may be shutter glasses, head mounted displays/headsets or passive polariz-

Fig. 4 HD camera head

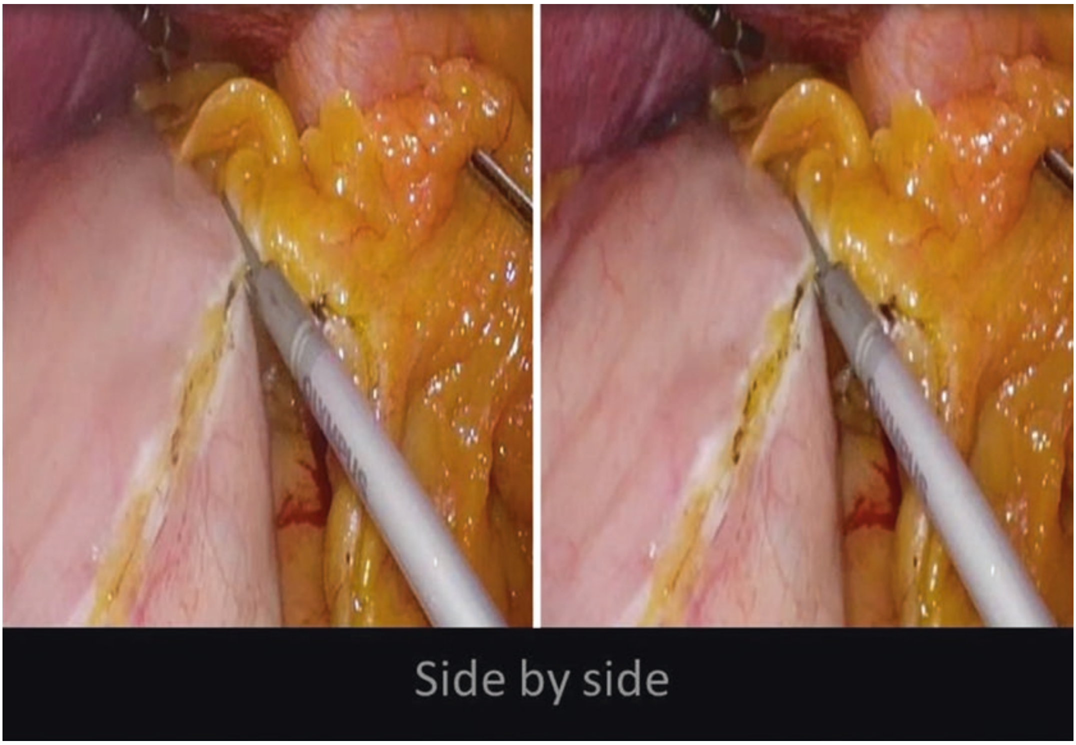

Fig. 5 Dual channel telescope with two images one for each eye

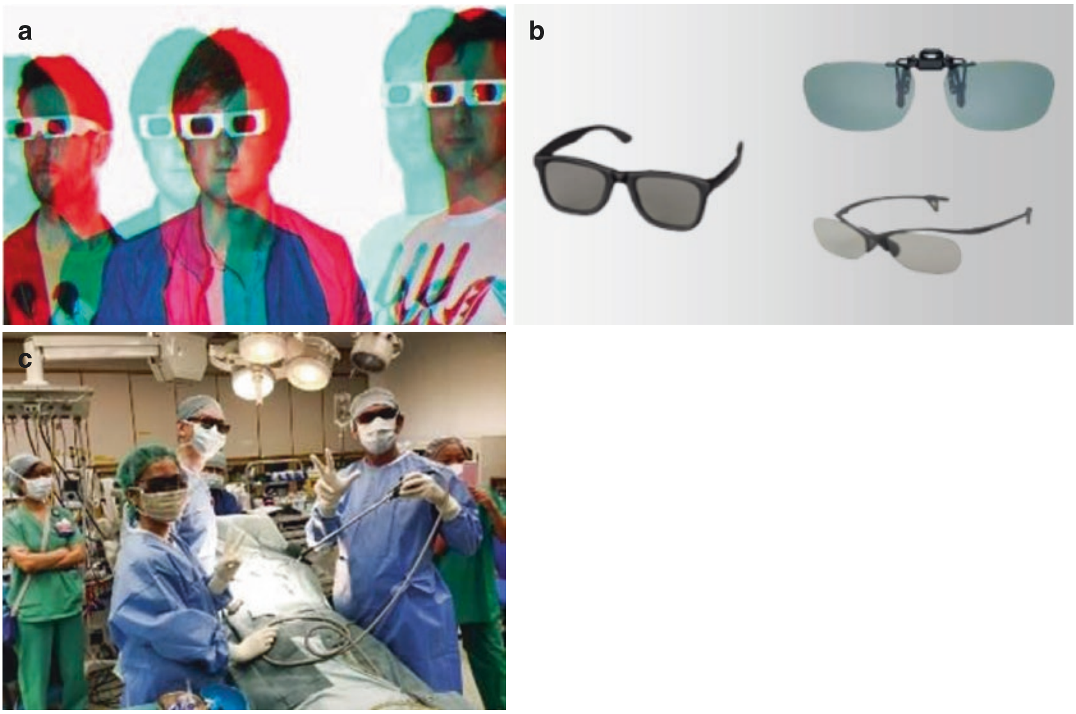

Fig. 6 (**a**) Anaglyph lens (not for medical use), (**b**) Passive polarization lens for medical use, (**c**) OR team wearing passive lenses

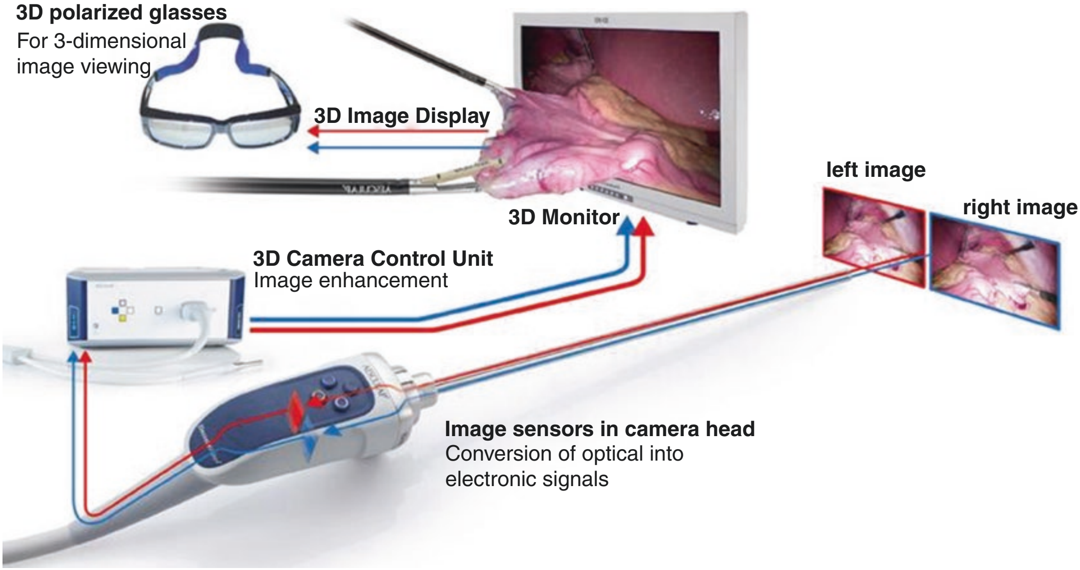

Fig. 7 3D technology in laparoscopy (Aesculap EinsteinVision®)

ing glasses are the most commonly utilized. Disadvantages of 3D laparoscopy involve a higher cost of video systems, need to wear 3D glasses, and eye fatigues even though the evolution of a new 3D system in the last decade have reduced most of the side effects and improved sensibly the quality of the image (Fig. 7). On the other side better accuracy and performance, easier depth judgment, and better identification of structure at different depth levels have been shown in several studies that improve significantly surgical performance, reduce fatigue, and are helpful in demanding tasks like suturing and fine dissection with an overall reduced time for skills acquisition.

Similar to a fixed 0° 3D telescope, there was a development of a flexible tip fiberoptic telescope to overcome the lack of angled vision (Fig. 8).

The challenges of 3D Image adoption and the evolution in imaging for both professional and consumers has also evolved in the medical field with the advent of 4 K technology. After an initial shifting from standard definition to high definition (1920×1080) today more surgeons utilized the 4 K technology in which resolution is 3840×2160 that allow the use of larger monitor (40″–65″ and bigger) with an incredible perception of the fine anatomical details. Fine structure that is used to be blurred in HD become clearer in 4 K and no more pixelation effect on the large monitors. This indirectly provides a better depth perception due to improved clarity and light reaction to the anatomic structures.

Fig. 8 Flexible tip telescope for angled vision

Certainly, evolution will continue for surgical imaging with 8 K in development and may be further higher resolution to provide an even better visual experience superior to reality.

Controller Unit

The function of the controller unit is to capture and process the video signals taken by the telescope and camera head to the video monitor to provide an accurate visualization of the operative field. It also functions to convert gathered video signals to digital HD images or downgrade it to standard definition (SD) images.

The control unit is attached to the camera head in its front console while connections to the video monitor are at the back panel. Connection to the

Fig. 9 Video system center unit with both image processor and light source

video monitor is in the form of digital cables which are the digital video interface (DVI) for the HD image and the serial digital interface (SDI) for the SD image. Newer controller units combine both image processor and light source functions in one unit (Fig. 9).

Video Monitor

High-resolution liquid crystal display (LCD) monitors are suitable for the reproduction of endoscopic image. This is a type of monitor wherein grids of liquid crystals are arranged in RGB (red-green-blue) triads in front of a light source to produce an image. In general, the resolution capability of the monitor should match that of the video camera. Three chip cameras require monitors with 800–900 lines of resolution to realize the improved resolution of the extra chip sensors. Two separate monitors on each side of the table are commonly used for laparoscopic procedures. The use of special video carts for housing the monitor and other video equipment allows greater flexibility and maneuverability.

A larger screen displaying the same number of pixels will have a lower spatial resolution compared to a smaller screen since the resolution is dependent on the pixel density. The advantage of ultra high definition UHD-4 K technology in laparoscopy monitors is it allows the image to be displayed on a larger screen of up to 55 in without compromising the resolution of 4098 × 2160 pixels (Fig. 10). Larger 4 K screens are available in different sizes ranging from 40–55 in. This optimizes the surgeon's performance in minimally invasive surgery. With these features, 4 K systems are being used as an alternative to the passive polarizing 3D display systems.

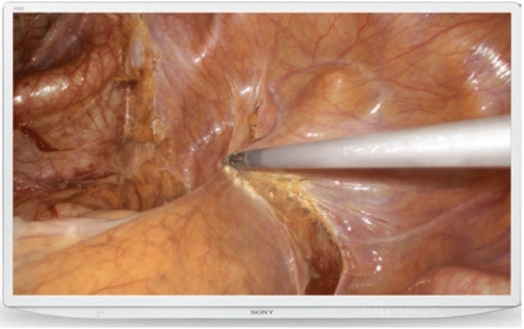

Fig. 10 4 K image quality

Fig. 11 LED video monitor

Some medical-grade monitors are now equipped with LED (light-emitting diode) or OLED (organic light-emitting diode) technology. LED monitors (Fig. 11) also feature a liquid crystal display panel to control where light is displayed on the screen, but the backlighting is produced using more efficient LEDs instead of fluorescent lamps. When used in endo-laparoscopy, these monitors are able to produce an extremely detailed image representation of the operative field. They offer several advantages which include high resolution, excellent image response times, and more precise and faithful color reproduction compared to traditional LCD monitors.

Documentation

A video recorder or a printer can be utilized for documentation during a surgical procedure. Today, both digital videos and images can be captured either on a medium like CD-DVD or digitally like a hard drive, USB, etc. The standard documentation equipment housed in the video card has multiple functions. First, a digitally recorded file can be transferred to an optical media device such as a digital video disc (DVD). Second, video snapshots taken during a procedure can be printed on a digital printer.

Recent technology available for intraoperative documentation provides full HD for still/video images along with two-channel, simultaneous real-time recording. It has the capability of processing records, managing images as well as editing (Fig. 12).

Integrated Operating Room

As surgical equipment continues to modernize, advanced operating theaters (OT) are now using systems integration (Fig. 13). This functionally connects the OT environment including the patient information system, audio, video, surgical lights, and other aspects of building automation. When integrated, all the technology used in the OT can be controlled through a single command console by a single operator. This provides seamless connections between equipment and personnel inside and out of the OT. To improve the space within the OT, devices are mounted on movable arms or carts that can swing around the patient to optimize visualization. These mounts allow proper positioning of the monitors and image systems in relation to the different areas of the patient's body during a surgical procedure. Integration allows not only a centralized control of the different units but also interaction with any external party like Meeting Rooms, Conference Centre, or for any other educational purpose. This avoids unnecessary visitors within the sterile operating field.

Fig. 12 Image management hub

Fig. 13 Example of integrated operating room (Hexavue™ Integration System)

Further Reading

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