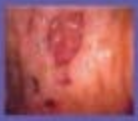

Practical Pediatric Gastrointestinal Endoscopy

George Gershman
and Marvin Ament

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Practical Pediatric Gastrointestinal Endoscopy

To my life muse, my wife Irina, my talented daughter Zhenya, and in memory of my remarkable parents.

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Practical Pediatric Gastrointestinal Endoscopy

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Introduction

1

In the late 1960s and early 1970s, sporadic attempts to perform esophagogastroduodenoscopy (EGD) using fiberscopes designed for adults were made in children. However, the actual "birth" of pediatric EGD occurred a few years later when prototypes of pediatric flexible gastroscopes and panendoscopes became commercially available. Subsequently, the pediatric community received unequivocal evidence of very low rates of complications related to upper gastrointestinal (GI) endoscopy, high diagnostic yields, cost-effectiveness due to safe use of the procedure in outpatient settings, and the ability to perform a variety of therapeutic procedures successfully adopted from adult GI practice. This led to widespread use of EGD in pediatrics.

Flexible GI endoscopy is a unique method of investigation of the GI tract in real time. It links direct observation of the object, with or without magnification and application of different dyes, with target biopsy, ultrasound technique, and variety of therapeutic procedures. It is an invasive procedure by definition. When applied to pediatric patients, safety becomes a major priority. In order to minimize morbidity associated with pediatric GI endoscopy, the endoscopist, especially the beginner, should learn all technical aspects of the procedure including the following:

- Endoscopic equipment such as endoscopes, light sources, biopsy forceps, snares, graspers, needles, electrosurgical devices, and all other accessories.
- Appropriate setting of the endoscopic equipment and doses of commonly used medications and solutions such as epinephrine, glucagon, and sclerosing agents.
- Proper techniques of diagnostic and therapeutic procedures.

The endoscopist should also become familiar with age-related anatomic variations of the GI tract and specific responses of the central nervous system, respiratory, and cardiovascular systems to artificial conditions created by the procedure itself. These include intubations of the esophagus, increased intra-abdominal pressure, elevation of the diaphragm, and stretching of the mesentery.

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2 Settings and Staff

THE ENDOSCOPY UNIT

Pediatric gastrointestinal (GI) endoscopy can be performed in an inpatient or outpatient endoscopy unit, at the patient's bedside, and in the operating room.

The endoscopy unit is usually designated for elective procedures. Typically, it has five functional areas:

- The preprocedure area consists of two major spaces:
  One is a dedicated waiting and reception area.
  The other serves as a space where parental consent can be obtained, the patient can be undressed and examined, and intravenous (IV) access may be established.
- Procedure area with examining rooms
- Recovery area
- Staff area with a work station for units with more than three rooms
- Storage space and a section dedicated to cleaning and disinfections of endoscopes.

Except in children's hospitals, the volume of pediatric procedure is usually not enough to run a separate endoscopic GI unit. Frequently, pediatric GI procedures must be scheduled and performed in the endoscopy unit shared with adult gastroenterologists.

Endoscopy units that are shared between pediatric and adult gastroenterologists must have a nursing and ancillary supporting staff that is comfortable and trained to work with both children and adults. They must recognize the difference in the needs of the patients. Although some units that serve both adults and children may dedicate a special room for pediatric patients, it is far more flexible for all rooms to be equipped to work with both children and adults.

Most pediatric bedside endoscopy is done in intensive care units because of the critical state of the patients. Bedside pediatric endoscopy is typically limited to children with acute GI bleeding or complicated recovery after bone-marrow or solid organ transplantation, those who are in isolation, admitted to pediatric, neonatal intensive care units, or pediatric emergency department. It is usually a complex and labor-intensive procedure in critically ill patients, which requires

1 full cooperation between skilled endoscopist, residents, endoscopy nurses, and attending pediatric physician or intensivist;

2 good functional conditions of all endoscopic equipment;
3 a well-organized and appropriately equipped mobile endoscopy station.

The mobile station should be loaded with a light source, electrosurgical unit, biopsy forceps, retractable needles, polypectomy snares, graspers, rubber bands, epinephrine, sclerosants, different sizes bite-guards, biopsy mounting sets, fixatives, culture media, cytology brushes, and slides. The bedside area should be spacious enough to accommodate the endoscopic station, a portable monitor, and equipment for general anesthesia. Two separate suction canisters should be available for endoscopy and oral or tracheal aspiration.

The position of the bed should be adjusted for the height of the endoscopist and special indication for the procedure; for example, reverse Trendelenburg position is advantageous for patients with acute GI bleeding to reduce the risk of aspiration and to improve visibility of the cardia and subcardia areas in children with stress ulcer, which is not uncommon after neuro- or cardiac surgery. A similar position may be useful for patients with GI bleeding due to portal hypertension and gastric varices. Endoscopic procedures in the neonatal intensive care unit should be performed under a warmer.

Pediatric GI endoscopy in the operating room is restricted to children with obscure GI bleeding, Peutz-Jeghers syndrome, or other circumstances, which require intraoperative enteroscopy or precise localization of the gastrointestinal lesions or assistance during surgery; for example, a placement of the string for retrograde bouginage of esophageal stricture. The endoscopy team should be familiar with the operating room environment and regulations.

PEDIATRIC ENDOSCOPY NURSE

A well-trained nurse is the key to a successful pediatric endoscopy team. This individual should be skilled in many areas such as:

1 How to communicate with the parents and the child in order to decrease the degree of stress and anxiety before the procedure;
2 Knowing how to establish and secure IV access before and, if necessary, during the procedure;
3 Preparing of all monitoring devices including EKG leads, pulse oximeter sensors, blood pressure cuffs appropriate for the child's size, and life support equipment such as nasal cannulas, proper size oxygen masks, ambu-bags, and intubation tray;
4 Selecting and preparing appropriate endoscopic equipment for the procedure;

5 Knowing how to monitor patients during sedation, procedure, and recovery;
6 Knowing how to properly mount the biopsy specimens and preparation of the cytological slides;
7 Being skillful in mechanical and chemical cleansing of the equipment and disinfection of the working space;
8 Quality control maintenance.

It is a great help to have such a nurse on call 24 hours a day.

DISINFECTIONS OF THE ENDOSCOPES AND ACCESSORIES

Thorough mechanical cleaning of the endoscope and nondisposable instruments is an essential part of any procedure, but especially a bedside endoscopy. It is an important initial phase of disinfection and also quite an effective preventive measure against clogging of the air/water channel and future mechanical failure of very expensive endoscopes. The final cleaning of the instruments is usually performed with glutaraldehyde, which destroys viruses and bacteria within a few minutes. Endoscopes are allowed to soak typically for a 20-minute period, although high-risk situations including known or suspected mycobacterial infection may require longer periods of time. The chemical itself can exacerbate reactive airway disease, asthma, or dermatitis in predisposed patients or staff. For this reason, instruments are thoroughly rinsed in water and allowed to dry prior to their next use. Air/water and suction channels are further rinsed in a solution containing 70% alcohol and also require compressed air drying to prevent bacterial growth. Instruments should be hung and stored in a vertical position in a well-ventilated cupboard to ensure dryness and minimize chance of bacterial growth.

More detailed description of disinfection technique is presented in Chapter 3.

DOCUMENTATION

Different types of photodocumentation are available during endoscopy. The films or Polaroid photographs of the findings seen at endoscopy have been replaced with digital photo printers in early 1990s. A real-time videotaping is the least practical but currently the cheapest method. It used to be popular for teaching purpose. Although a digital transformation of VHS recording into the laser disk with subsequent snapshot images is now feasible, it is going to be replaced soon with DVD recorders specifically designed for endoscopic procedures.

A modern digital file system allows the endoscopist to store and print quality digital prints on a regular paper, although such equipment is costly and not routinely available. It also allows

one to generate the report of just-completed procedures and supplement the medical chart with important descriptive and visual information.

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3 Equipment

OVERVIEW

The modern video endoscope is the result of more than two decades of refinements in solid-state imaging technology and mechanical design. The basic shape, controls, and method of use are relatively unchanged from fiberoptic endoscopes used in the mid-1970s. Although alternative designs for the control section have been proposed (e.g., "pistol-grip" controls), the basic layout of the gastrointestinal (GI) endoscope is similar across all models (gastroscopes, colonoscopes, etc.) and all manufacturers. The basic components and controls of the video endoscope are illustrated in Fig. 3.1. The instrument is designed to be held and operated by the endoscopist's left hand, while the endoscopist's right hand primarily controls the insertion tube – pushing, torquing, advancing, and withdrawing as necessary.

INSERTION TUBE

Although the control section of various endoscope models is similar, it is primarily the length and flexibility of the insertion tube that distinguishes a gastroscope from a colonoscope, and it is the physical dimensions of the insertion tube (outer diameter, channel diameter, etc.) that distinguishes one model of endoscope from another. Figure 3.2 illustrates the internal components of a typical videoscope insertion tube. Both gastroscopes and colonoscopes employ similar components. While the insertion tube's outward appearance is deceptively plain, internally it is filled with a collection of tubes, control wires, electrical wires, glass fibers, and other components. The largest internal tube housed in the insertion tube is typically the instrument "channel" and is used for suctioning fluid and taking biopsies. Smaller internal tubes are used to convey air and water for insufflation and lens washing, respectively. Some models, more often colonoscopes, have an additional forward water-jet tube for washing the lumen wall. As Fig. 3.2 illustrates, four angulation control wires run the length of the insertion tube. These are used to control the deflection of the distal tip. A group of very fine electrical wires connects the CCD (charge-coupled device) image sensor at the distal tip of the endoscope to the video processor. These wires are housed in a protective sheath to prevent them from being damaged as the instrument is manipulated. One or two

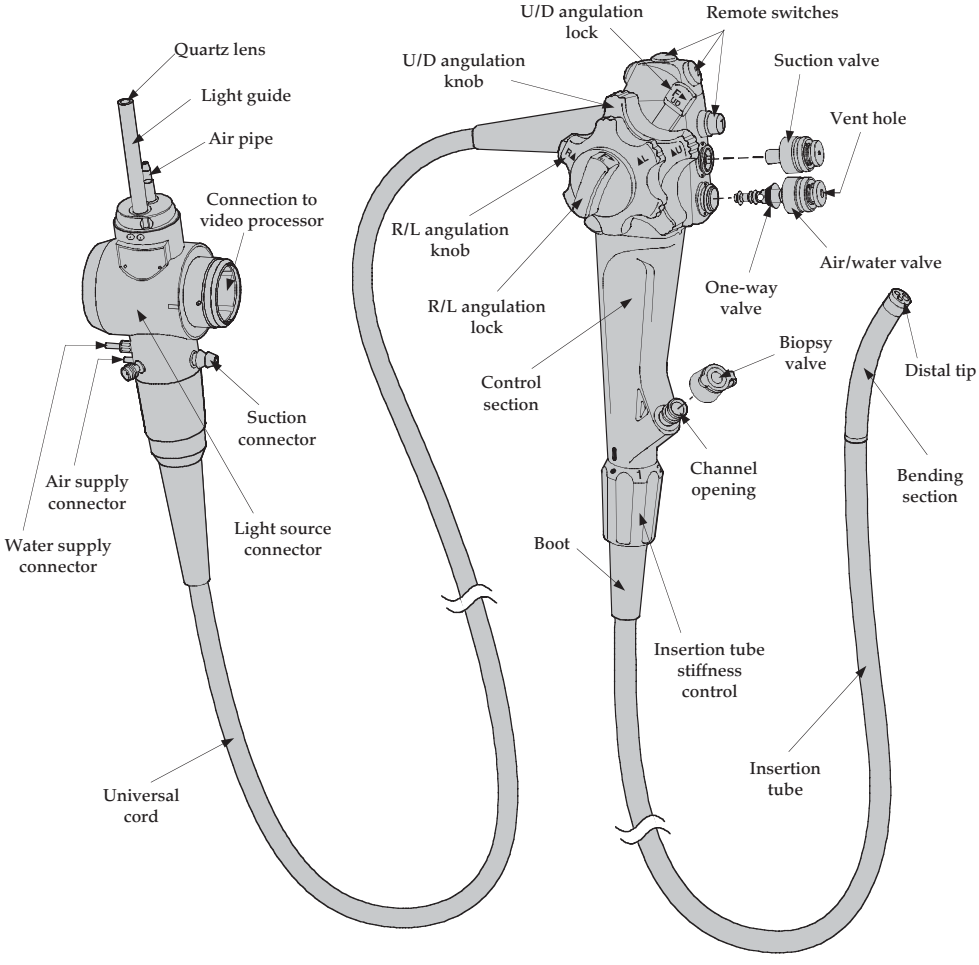

Fig. 3.1 Colonoscope – components and controls. Gastroscopes have a similar construction.

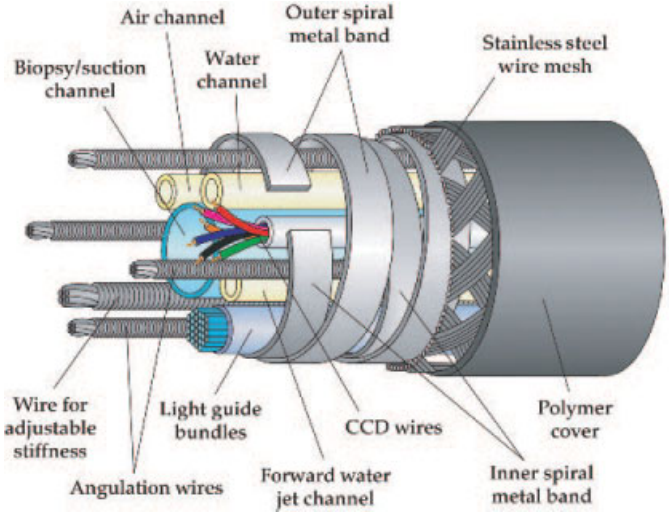

Fig. 3.2 Insertion tube – internal components and construction.

bundles of delicate glass fibers also run the length of the insertion tube, bringing light from the light source to the distal end of the endoscope. These fragile fiberoptic bundles also require protection and are enclosed in a soft flexible protective sheath. Colonoscopes with adjustable insertion tube flexibility have an additional component – a tensioning wire to control insertion tube stiffness.

The endoscope designer must pack all of these individual components into the smallest possible cross-sectional area in order to minimize the outer diameter of the insertion tube. A small insertion tube diameter is especially important in instruments used in pediatric endoscopy, but the components cannot be packed too tightly. The endoscope designer must plan for enough free space to permit the components to move about without damaging the more fragile components (e.g., CCD wires, fiberoptic strands) as the instrument is torqued and flexed during use. A dry powdered lubricant is applied to all internal components to reduce the frictional stress they place on each other during insertion tube manipulation.

Manufacturers typically advise that to avoid damage the endoscope should not be coiled tighter than a specific radius during use, reprocessing, and storage. Although overcoiling of the insertion tube may cause damage, more frequent causes of insertion tube damage are accidental crushing of the tube (e.g., patient bite, accidental closure in the carrying case hinge) and kinking at the boot where the insertion tube joins the control section (see Fig. 3.1).

Insertion tube flexibility

The handling characteristics of the insertion tube are extremely important. For ease of insertion, the instrument must be capable of accurately transmitting torque from one end of the tube to the other. Any rotation applied by the endoscopist to the proximal portion of the shaft must be transferred to the distal tip of the instrument in a 1:1 ratio. In order to transmit this torque and prevent the instrument shaft from simply twisting up, the insertion tube is built around several flat, spiral metal bands that run just under the skin of the insertion tube (see Fig. 3.2). Because these helical bands are wound in opposite directions, they lock against one another as the tube is torqued, accurately transmitting rotation of the proximal end of the tube to the distal end of the tube. At the same time, the gaps in the helical bands allow the shaft to flex freely. These metal bands also give the insertion tube its round shape and help prevent the internal components of the insertion tube from being crushed by external forces.

The helical bands are covered by a layer of fine stainless steel wire that has been braided into a tubular mesh. This mesh creates

a metal, fabric-like layer, which covers the sharp edges of the spiral bands, and creates a continuous surface upon which the outer layer of the tube can be applied. The external layer (observable to the user) is composed of a plastic polymer, typically black or dark green, which is extruded over the wire mesh to create a smooth outer surface for the insertion tube. The polymer layer provides an atraumatic, biocompatible, and watertight exterior for the insertion tube. It is usually marked with a scale to allow the endoscopist to gauge the depth of insertion. While each component of the insertion tube has some effect on the overall flexibility of the tube, the endoscope designer most often adjusts the construction of the wire mesh and the outer polymer layer to fine-tune the handling characteristics of the instrument.

Years of experience have shown that a more rigid insertion tube is optimal for examining the fixed anatomy of the upper GI tract. On the other hand, the colon, with its tortuosity and freely moving loops, is best examined by a more flexible instrument. Therefore, if one were to compare a colonoscope and a gastroscope side by side, one would find that overall the colonoscope insertion tube is much more flexible.

The ideal colonoscope insertion tube has to be flexible, yet highly elastic, and sufficiently floppy (nonrigid) to conform easily to the tortuous anatomy of the patient. It should not exert undue force on the colon or its attached mesentery. On the other hand, the instrument should have sufficient column strength to prevent buckling when the proximal end of the instrument is pushed. (In contrast, a wet noodle, which is also extremely flexible, has no column strength and collapses when pushed.) In addition to its flexibility, the colonoscope should have sufficient elasticity to pop back into a straightened condition whenever it is pulled back. This aids the endoscopist in removing colon loops. The goal in designing the proximal portion of the insertion tube, therefore, is to prevent the reformation of bowel loops as the instrument is advanced. Obtaining the best combination of flexibility, elasticity, column strength, and torqueability is the art and science of insertion tube design. Often times, improvements in one of these characteristics negatively impact one or more of the others. The final design is usually a compromise of these ideal characteristics, confirmed by months of clinical testing.

To improve the ability to insert both gastroscopes and colonoscopes, the flexibility of the insertion tube typically varies throughout its length. As Fig. 3.3 illustrates, the distal 40 cm of the colonoscope insertion tube is significantly more flexible than the proximal portion of the tube. This variation in flexibility from proximal end to distal end is achieved by changing the formulation of the tube's outer polymer layer as it is extruded over the underlying wire mesh during the manufacturing process. The

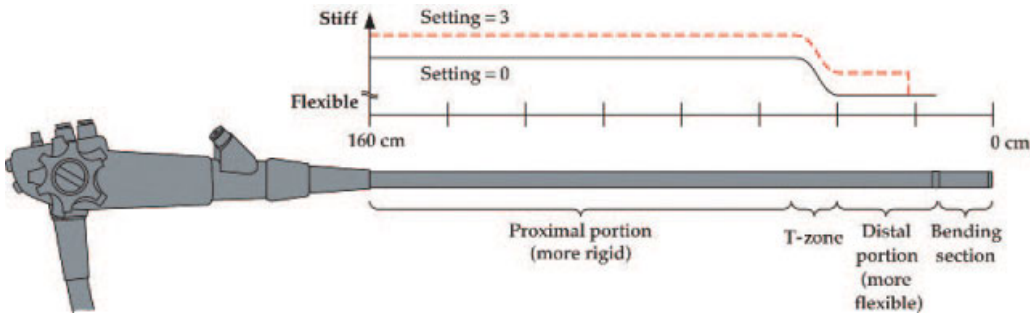

Fig. 3.3 The flexibility of the colonoscope insertion tube varies over its length. On some models it can be further stiffened by changing the setting on the adjustable stiffness control.

extrusion machine that manufactures the outer coating of the insertion tube contains two types of plastic resins, one significantly harder than the other. Initially, as the distal end of the insertion tube passes through the machine, a layer of soft resin is applied to distal 40 cm of the insertion tube. This soft resin is gradually replaced by the hard resin within a transition zone (T-zone in Fig. 3.3) near the middle of the tube. The remaining proximal portion of the insertion tube (50–160 cm) is constructed totally from the hard resin (Moriyama 2000). The end result is a colonoscope insertion tube that has a soft distal portion for atraumatically snaking through a tortuous colon, with a stiffer proximal portion that is effective at preventing loop reformation in those portions of the colon that have already been straightened by the instrument. The flexibility of a gastroscope's insertion also varies in a similar manner – being more flexible at the distal end and stiffer at the proximal end.

Clinical experience has shown that endoscopists may disagree over what constitutes an insertion tube with "ideal" physical characteristics. This may be due to the differences in the endoscopist's training, insertion technique, and past experience. In addition, some endoscopists have expressed a desire to change the characteristics of the insertion tube during the procedure itself, based on insertion depth or the patient's anatomy. This has led to the development of an insertion tube with adjustable stiffness (Moriyama 2001). Colonoscopes with adjustable stiffness have a tensioning wire that runs the length of the insertion tube (see Fig. 3.2). The amount of tension in this wire is controlled by rotating a ring at the proximal end of the insertion tube, just below the control section (see Fig. 3.1). When the inner wire in the stiffening system is in the "soft" position, the stiffening system provides no additional stiffness to the insertion tube beyond that provided by the wire mesh and polymer coat. When the control ring is rotated to one of the "hard" positions, the pull wire is retracted and

placed under heavy tension. This stiffens the coil wire surrounding the pull wire and adds significant rigidity to the insertion tube. As Fig. 3.3 summarizes, the base stiffness of the insertion tube (Setting = 0) is established by varying the mixture of hard and soft resins in the outer polymer coat of the insertion tube. This base stiffness, however, can be further enhanced by increasing the tension in the variable stiffness pull wire (Setting = 3).

Distal tip

The distal tip of all end-viewing endoscopes (e.g., gastroscopes and colonoscopes) is constructed of the components illustrated in Fig. 3.4. Light to illuminate the interior of the body is carried through the instrument via a bundle(s) of delicate fiberoptic illumination fibers. Each of these glass fibers is approximately 30 μm in diameter. A lens at the tip of this fiberoptic bundle evenly disperses the transmitted light across the endoscope's field of view. It is important to achieve even and balanced illumination across the entire viewing field for good video imaging. Some endoscopes have a single illumination bundle. Larger diameter models may have two fiberoptic bundles and two light guide lens systems to improve illumination on both sides of the biopsy forceps (snare, etc.) and to facilitate the packing of components within the insertion tube.

The CCD unit, the solid-state image sensor that creates the endoscopic image, is located in the distal tip just behind the objective lens of the endoscope. The objective lens is typically the largest lens on the tip of the instrument. The CCD image sensor captures and sends a continuous stream of images back to the video processor for display on a video monitor. The objective lens and CCD unit must be completely sealed to prevent

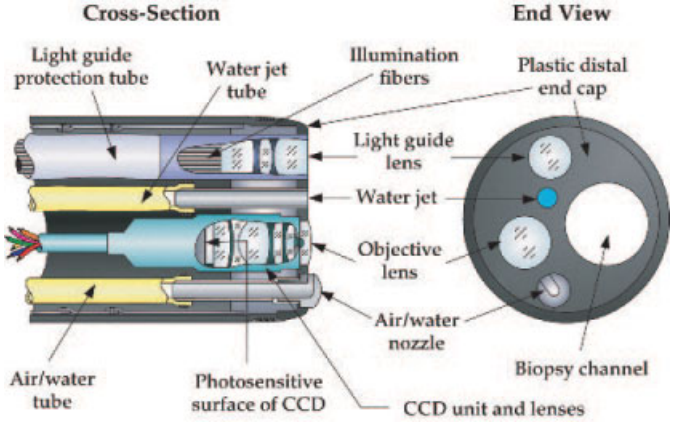

Fig. 3.4 Endoscope distal tip – typical components and construction.

condensation from fogging the image and to protect the imaging system from damage if fluid were to accidentally enter the endoscope. Care should be taken in handling the endoscope to prevent the distal tip from hitting the floor, the equipment cart, or any other hard object. If the objective lens is cracked, fluid can invade the CCD unit, requiring an expensive repair. It is also important to avoid scratching the objective lens as this will reduce the clarity of the endoscopic image.

The channel used for biopsy and suction exits the distal tip close to the objective lens. The relative positions of the biopsy channel and the objective lens determine how accessories will appear in the endoscopic image as they enter the visual field. On some model endoscopes, the snare (biopsy forceps, etc.) appears to emerge from the lower right corner of the image. On other model instruments, these accessories enter the visual field from the lower left corner, and so forth, depending on the relationship of the channel to the viewing optics.

Air for insufflation and water for lens washing travel through the insertion tube in separate small tubes. However, to conserve space and to exit through a single nozzle, these tubes typically merge into a single tube just prior to the bending section of the instrument (see Fig. 3.6). This combined air/water tube then connects to the air/water nozzle on the tip of the instrument (see Fig. 3.4). Under control of the endoscopist, water can be fed across the objective lens to clean it, and air can be fed from the same nozzle for insufflation. Some endoscopes (more commonly colonoscopes) have an additional water tube and water-jet nozzle on their distal tip for washing the lumen wall (see Fig. 3.4). In earlier years, pediatric colonoscopes often eliminated some of the functions of standard colonoscopes in order to minimize their size. Improvements in technology have allowed many pediatric colonoscopes to now have functions such as water-jet nozzles, adjustable stiffness controls, and high density CCDs just like their standard sized counterparts.

Bending section and angulation system

The distal-most 7–9 cm of the insertion tube can be angulated under the control of the endoscopist to look around corners or view lesions *en face*. This deflectable portion of the instrument is referred to as the bending section and, as Fig. 3.5 illustrates, is constructed quite differently from the rest of the insertion tube. The bending section is able to bend freely because it is composed of a series of metal rings, each one connected to the ring both immediately preceding it and following it via freely moving joints. These joints consist of a series of pivot pins, each one displaced from its neighbors by 90°. This construction allows the bending section of the endoscope to curl in any direction, often up to a

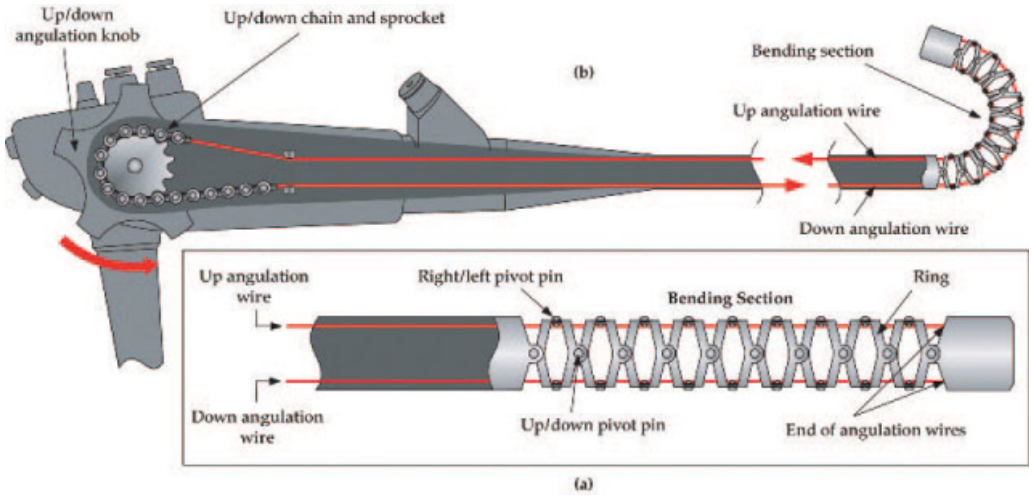

Fig. 3.5 Construction of bending section and angulation system.

maximum of 180– 210°. The direction of the curl is controlled by four angulation wires running the length of the insertion tube (see Fig. 3.2). These four wires are firmly attached to the distal end of the bending section in the 3, 6, 9, and 12 o'clock positions. Pulling on the wire attached at the 12 o'clock position will cause the bending section to curl in the UP direction. Pulling on the wire attached at the 3 o'clock position will cause the tip to deflect to the RIGHT. Pulling the other two wires will cause DOWN and LEFT deflections.

These wires are pulled by rotating either the up/down or right/left angulation knobs. (For simplicity, Fig. 3.5 illustrates only the up/down angulation system.) Rotating both knobs together will produce a combined tip movement (e.g., upward and to the right). By using the two angulation knobs simultaneously, the endoscopist can sweep the tip of the endoscope in any direction. Colonoscopes typically have 180° of deflection in the up and down directions. Deflection in the right and left directions is typically limited to 160° to avoid overstressing the internal components of the instrument. Gastroscopes typically have a much tighter bending radius and can achieve a full 210° deflection of the tip in the UP direction – ideal for examining the gastroesophageal junction from a retroflexed position.

Air, water, and suction systems

A schematic of the typical system used for air, water, and suction is shown in Fig. 3.6. Air under mild pressure is supplied by an air pump in the light source to a pipe protruding from the

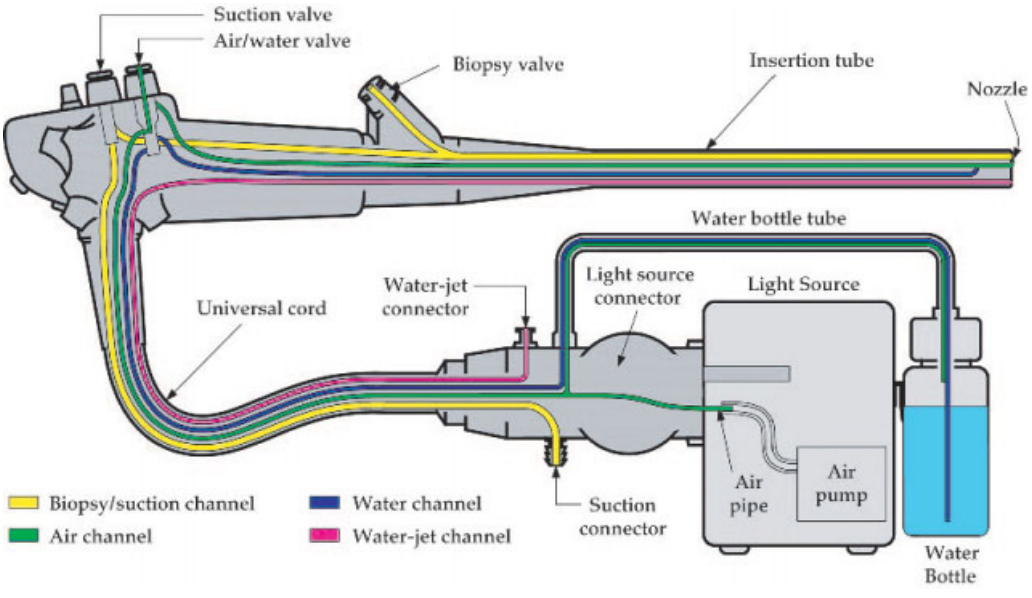

Fig. 3.6 Schematic of a typical endoscope air, water, and suction system.

endoscope's light source connector. This air is directed via the air channel tube to the air/water valve on the control section. If this valve is not covered, the air simply exits from a hole in the top of the valve (see Fig. 3.1). Continuously venting the system via this hole reduces wear and tear on the pump. To insufflate the patient, the endoscopist simply covers the vent hole with the tip of a finger. This closes the vent and causes air pressure to immediately build up inside the air-feeding system. With the vent closed, air is forced down the air channel tube and exits the endoscope through the nozzle on the distal tip. The maximum flow out of the tip of the instrument is typically around 30 cm^3/s.

A one-way valve is incorporated into the shaft of the air/water valve (see Fig. 3.1). This antireflux valve is necessary to hold air in the patient while insufflated. If it were not for this one-way valve in the system, air from the patient would flow back into the air nozzle, up the insertion tube, and out of the hole in the air/water valve whenever the operator's finger is lifted off the valve.

Water, used to clean the objective lens of the endoscope during the procedure, is stored in a water bottle attached to the light source or cart (see Fig. 3.6). In addition to feeding air for insufflation, the air pump also pressurizes this water container. This forces water out of the bottle and up the universal cord to the air/water valve. When the endoscopist depresses the air/water valve, it allows the water to continue down the water channel

in the insertion tube and out of the nozzle on the distal tip. The nozzle then directs this water across the surface of the objective lens to clean the lens.

In a similar manner, suction is also controlled by a valve. A suction line, either from a portable suction pump or from the hospital's house suction system, is connected to the endoscope. A slight vacuum is applied to the suction channel in the universal cord. When the endoscopist depresses the suction valve, suction is further applied to the suction–biopsy channel within the insertion tube. The proximal opening of the biopsy channel is closed off by a biopsy valve. This prevents room air from being drawn into the suction collection system. Any fluid (or air) present at the distal tip of the endoscope, however, will be drawn into the suction collection system under the control of the endoscopist.

There are several inherent safety features in the design of the air, water, and suction system shown in Fig. 3.6, including the following: (i) There is no air valve in the system which could stick in the "on" position – resulting in accidental overinsufflation of the patient. Rather the air simply exits the vent hole in the valve unless the physician has his or her finger over the opening. (ii) In the event that the suction system becomes obstructed and the endoscopist has difficulty with possible overinsufflation, he or she can simply quickly remove all valves from the endoscope. This will stop all supply of air and water, and will allow the patient's GI tract to depressurize through the open valve cylinders.

Illumination system

Video endoscopes bring light into the interior of the body via an incoherent fiberoptic bundle. This fiber bundle is composed of thousands of hair-like glass fibers, each one only 30 μm in diameter, and carries light from the external light source to the distal tip of the endoscope. Each fiber is optically coated along its length to trap light within the fiber and thereby transmit it from end to end. Light rays entering one end of such a fiber reflect off of the walls of the fiber many thousands of times as they travel the length of the fiber through a process referred to as *total internal reflection*. The types of glass used to make the core and cladding of the fiber, and the dimensions of the core and cladding are all carefully selected to enable the fiber bundle to carry as much light as possible (see Kawahara 2000 for a more complete discussion of fiber optics).

Older model light sources for flexible fiberscopes often utilized halogen lamps that emitted a yellowish light. Modern endoscopic light sources typically employ 300-W xenon arc lamps to produce the bright, white light required for video imaging. These lamps also produce considerable heat. Heat sinks, infrared filters, and forced-air cooling systems within the light source

prevent the light guide fiber bundle from overheating and burning. A burn-resistant quartz lens at the tip of the light guide bundle collects light from the light source lamp and directs it into the endoscope (see Fig. 3.1). At the other end of the endoscope, the light guide lens at the distal tip of the instrument spreads this light uniformly over the visual field (see Fig. 3.4). An automatically controlled aperture (iris) in the light source controls the intensity of the light emitted from the endoscope. When the endoscope is in the body of the stomach and significant light is required to produce a bright image, the aperture in the light source opens up, allowing the endoscope to transmit maximum light. On the other hand, when the endoscope tip is very close to the mucosa and illumination is very bright, the aperture automatically closes down to reduce the amount of light exiting the light source. If illumination of the tissue is too low, the image on the monitor will be dark and grainy. On the other hand, if the illumination is too strong, the image on the monitor will be washed out (i.e., "bloom"). The light source and video processor work together to automatically maintain the illumination at an ideal level for the CCD image sensor.

VIDEO IMAGE CAPTURE

The image sensors used in video endoscopes are typically referred to as CCDs. These sensors are solid-state imaging devices made of silicon semiconductor material. The silicon on the surface of the sensor responds to light and exhibits a phenomenon called the *photoelectric effect*. As Fig. 3.7 illustrates, when a photon of light strikes the photosensitive surface of the CCD, it displaces an electron from a silicon atom in the material. This produces a free, negatively charged electron and a corresponding positively charged "hole" in the crystalline structure of the silicon at the location where the electron was previously bound. As photons hit

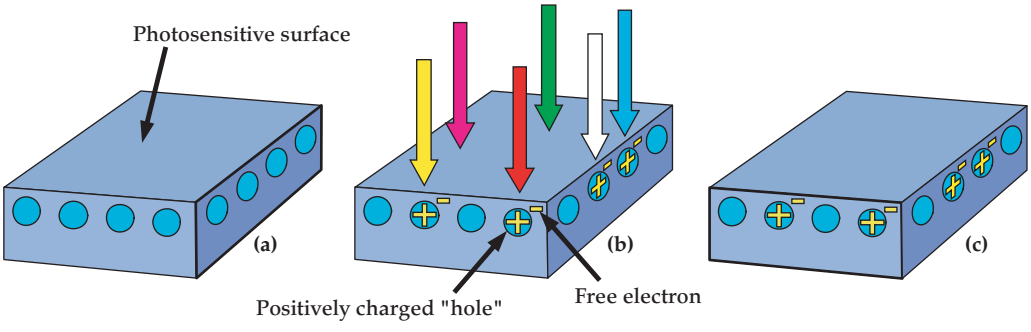

Fig. 3.7 The photoelectric effect – transforming light into electrical charges.

the surface of the sensor, free electrons and corresponding holes are generated (Fig. 3.7b). These charges remain in the sensor after the illumination ends (Fig. 3.7c). The charges built up on the surface of the sensor are directly proportional to the amount of light which fell on the CCD.

A single photosensitive element is valuable in that can be used to measure the overall brightness of the light falling on the device (as in a light meter). However, it cannot reproduce an image. In order to reproduce an image, the brightness of every point in the image must be measured. To do this the photosensitive surface upon which the image is projected must be divided up into a matrix of thousands of small, independent photosites. When an image is focused on the surface of such a sensor, the brightness of the image can be automatically measured at each individual photosite. Knowing the brightness of every point in the image allows the processing system to subsequently recreate the image on a viewing monitor.

All CCD sensors have a rectangular array of discrete photosites on the imaging surface. These photosites individually correspond to the picture elements or "pixels," which make up the image. Figure 3.8 illustrates a sensor with such an array of photosites. For simplicity, the array illustrated in Fig. 3.8 contains an 8-row by 8-column array, for a total of 64 pixels. In fact, the CCDs used in GI endoscopes typically contain several hundred thousand pixels. The greater the number of pixels on the CCD, the higher the resolution of the reproduced image.

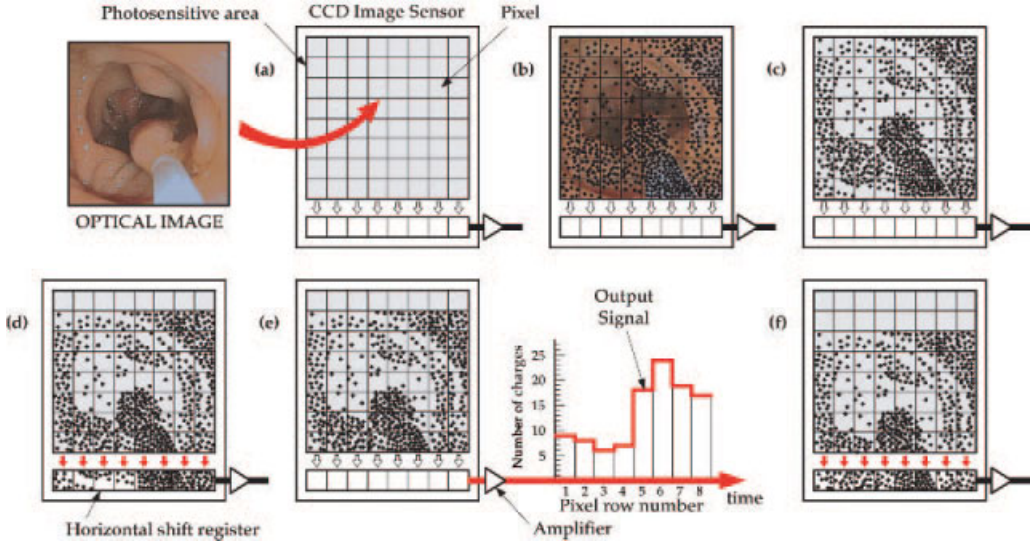

Fig. 3.8 Schematic representation of how a line transfer CCD captures an optical image. The "electrical representation" of the image is then read off in an orderly manner.

As illustrated in Fig. 3.4, the CCD is located in the distal tip of the endoscope directly behind the objective lens. The objective lens focuses a miniature image of the observed mucosa directly on the surface of this sensor (see Fig. 3.14). The pattern of light falling on the CCD (i.e., the image) is instantly converted into an array of stored electrical charges as a result of the previously described photoelectric effect. Because the charges stored in each of the individual pixels are isolated from the neighboring pixels, the sensor faithfully transforms the optical image into an electrical replica of the image. This electrical representation is then processed and sent to a video monitor for reproduction.

As Fig. 3.8 illustrates, pixels in dark areas of the image develop a low voltage due to the generation of fewer charges. Pixels in brighter areas of the image develop a proportionately higher voltage due to the creation of more electron/hole pairs in the crystalline structure of the silicon. The photoelectric process is linear. Doubling the number of photons of light falling on a pixel doubles the number of charges generated at the pixel until they reach the maximum storage capacity of the photosite. Through this process, the optical image is converted into an electrical replica of the image suitable for subsequent processing, display, printing, and archiving, all by electronic means.

"READING" THE IMAGE CREATED ON THE CCD

The first step in this process is to measure the brightness of each point in the image by systematically quantifying the number of charges generated in each photosite. After the CCD is exposed to the image, the charges developed in the CCD must be "read out" in an orderly manner, and then processed to create the dataset necessary to reproduce the original image. The methods used to create the charges, and then to read the charges, are schematically illustrated in Fig. 3.8. As shown in Fig. 3.8a, the first step in video image capture is to project an optical image of the mucosa onto the photosensitive surface of the CCD. Electrical charges are instantly developed at each photosite within the array, following brief exposure to the image (see Figs. 3.8b–c). (For simplicity, Fig. 3.8 illustrates an array with only a few pixels and only a few stored charges. These charges are represented by small dots within the photosites.)

The charges within each pixel are then controlled and shifted over the surface of the CCD via electrodes adjacent to each photosite. (These electrodes are not shown in the figure.) By varying the voltages applied to these electrodes, the electrons within individual photosites are transferred as "charge packets" from one pixel to another. Sequential voltage changes on these electrodes march the charges across the matrix toward the bottom

edge of the CCD and then into a horizontal shift register (see Fig. 3.8d). The charges in the horizontal shift register are then passed through an output amplifier and are converted into an output electrical signal. The output signal fluctuates in direct proportion to the number of charges stored in each pixel. At the point in the process illustrated in Fig. 3.8e, the bottom row of the original image is being read out and sent to the video processor for reconstruction. The electrical representation of the entire image has shifted down one row on the CCD.

Once the horizontal shift register has been read out and cleared (i.e., emptied), the remaining charges in the array are then sequentially transferred down to the pixel below, resulting in a second downward shift of the image replica. This step once again fills the horizontal shift register with charges – this time, charges that were originally in the second-to-the-bottom row of the array. The charges in the horizontal shift register are again read out, producing an output signal that is representative of the brightness of the image falling on the second-to-the-bottom row of the original image. The processing of the image replica continues, in a step-by-step fashion, until the entire CCD has been read out. Once the CCD is read and cleared, it is ready for another exposure.

The "charge-coupling" process – that is the transfer of charges from pixel to pixel as charge packets – gives the CCD its name ("charge-coupled device"). The charges in the furthermost corners of the CCD are actually moved sequentially through several hundred photosites before they reach the horizontal shift register. In current video endoscopes, the CCD is exposed, read out, and reexposed 60–90 times each second. To maintain image fidelity during these repetitive transfers, it is essential that these charge packets remain intact with no loss or gain in charge quantity as they undergo hundreds of thousands of transfers per second as the CCD is being read out.

The CCD illustrated in Fig. 3.8 is representative of a line transfer CCD. One characteristic of a line transfer CCD is that the photosensitive area of the CCD (the photosite array) must be shielded from light during the entire time that the image is being moved through the matrix and read out. If the CCD is exposed to additional light during the reading process, new charges generated at the photosites by the continuing illumination will mix with the charges generated by the previous image as they are being transferred through the photosite array. To preserve the original image, the photosites must be completely dark while the image replica is being transferred. One method of doing this in endoscopic applications is to strobe, or momentarily interrupt, the light emitted by the endoscope as the CCD is being read out. Strobing the light source creates a momentary burst of light to expose the image sensor, followed by momentary darkness as

the CCD is read out and cleared. Endoscopists who have used an RGB (red, green, and blue) sequential endoscopy system (typically called a "black-and-white" CCD system) are quite familiar with the concept of strobed endoscopic light sources.

TYPES OF CCDS

The line transfer CCD is just one type of CCD. There are, in fact, several different types of CCDs used in endoscopes today. The manner in which the charges are moved about within the CCD as they are read out depends upon the configuration (type) of the CCD employed. The three most common types of CCDs are the line transfer CCD, the frame transfer CCD, and the interline transfer CCD (Barlow 2000). Each of these designs has specific advantages in terms of the CCD's sensitivity to light (and in turn, the brightness required of the endoscope's illumination system), the type of light source required (strobed or nonstrobed), the physical size of the CCD (which in turn affects the diameter of the distal tip of the endoscope), and the speed at which the charges can be transferred out of the CCD.

As an alternative to the line transfer CCD, some video endoscopes utilize an interline CCD, an example of which is illustrated in Fig. 3.9. The interline CCD has a series of vertical shift registers placed adjacent to each column of photosites. Immediately after exposure to light (i.e., the image), the charges developed at the photosites are transferred in one quick simultaneous step to the adjacent vertical shift registers. Owing to the rapid, one-step transfer of charges, illumination of the CCD does not have to be interrupted, and the CCD can continue to

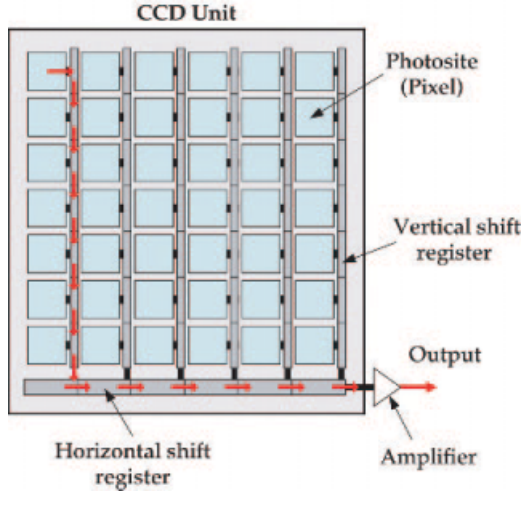

Fig. 3.9 Schematic of an interline transfer CCD.

collect light. In the meantime, the charges in the vertical shift registers are transferred, step by step, down to the horizontal shift register, where they are then read out in an orderly manner. (The red arrows in Fig. 3.9 illustrate the path taken by charges generated in the upper left corner pixel.) The vertical shift registers are shielded from light, allowing them to be emptied as the CCD is continuously exposed to light. The CCD thereby collects a second image as the first is being read. When the vertical shift registers are finally empty, a second newly created image replica in the sensor array is instantly transferred from the photosites to the vertical shift registers, and the process repeats.

A big advantage of the interline transfer CCD is that it does not require strobing of the illumination. Since the entire sensor array is cleared to the vertical shift registers in one quick step, the sensor array is immediately ready to capture the next image. So-called "color-chip" endoscopes that use continuous, nonstrobed light sources are examples of interline transfer CCD systems.

HISTORY OF ENDOSCOPE CCD DEVELOPMENT

The first video endoscope system was introduced in 1983 by Welch Allyn (Sivak 1984). The video endoscope became a reality when advancements in image sensor technology allowed the CCDs used in handheld video cameras to be reduced to a size that would fit within the distal tip of an endoscope. Since then, technology has continued to advance, allowing for further reductions in the physical size of the CCD, while at the same time increasing the number of pixels in the sensor array. This has enabled video endoscopes to become progressively thinner, with larger channels and higher resolution, with each new generation. Figure 3.10 illustrates the progress that has been over the last 17 years in variously reducing the size of the CCD and increasing the resolution of the image sensor. The CCD in Fig. 3.10b is smaller in size, yet has the same resolution as the CCD in

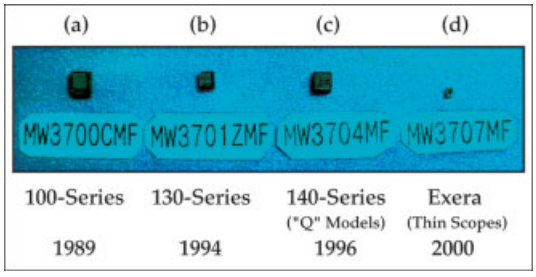

Fig. 3.10 History of CCDs used in Olympus EVIS and EXERA color-chip endoscopes.

Fig. 3.10a. The CCD in Fig. 3.10c is approximately the same size as the one shown in Fig. 3.10a, but has much greater resolution. The CCD in Fig. 3.10d is the world's smallest endoscopic CCD and is used in the very thinnest video endoscopes.

SHAPE OF DISPLAYED IMAGE

When observing the various makes and models of endoscopes on the market to date, one will note that they produce video images in a variety of overall shapes and sizes. All endoscopes emit a conical beam of light from their distal tip (see Fig. 3.14). In a similar manner, the round objective lens at the tip of the instrument produces a circular image of the tissue being viewed. Because of these geometric considerations, fiberoptic endoscopes typically use round image fiber bundles, and produce a round endoscopic image in the fiberscope's eyepiece.

In contrast, the rectangular matrix of photosites found on CCDs dictates that the photosensitive area of a CCD is always square or rectangular – since all CCDs use an array consisting of columns and rows to capture and transfer charges. The manner in which the video endoscope designer attempts to make best use of the mismatch between the round endoscopic image and the square/rectangular image sensor determines the shape of the endoscopic image as it appears on the video monitor. Figure 3.11a illustrates how the objective lens at the tip of the endoscope

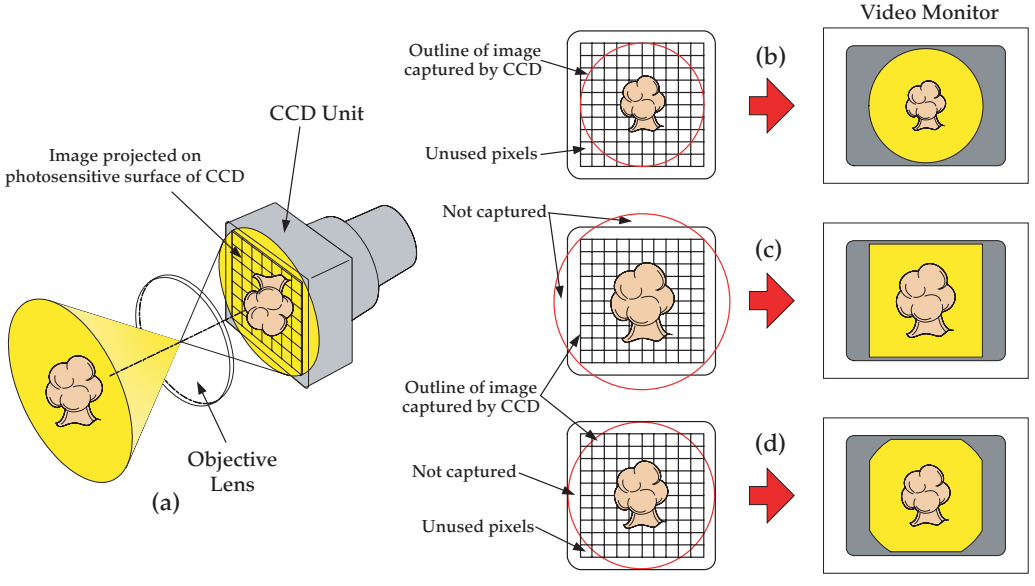

Fig. 3.11 The design and magnification of the objective lens affect the shape of the image displayed on the monitor.

creates an image of the GI mucosa on the photosensitive surface of the CCD. The endoscope designer can choose to project a small image on the CCD (Fig. 3.11b), a large image on the CCD (Fig. 3.11c), or an intermediate-sized image on the CCD (Fig. 3.11d). If the magnification of the distal lens system is adjusted to fit the endoscopic image entirely within the borders of the photosensitive area, then a round endoscopic image will be captured and reproduced on the observation monitor. This is illustrated in Fig. 3.11b. The advantage of this design is that the entire wide-angle view of the endoscope is fully observable. The disadvantages are that the image on the monitor is relatively small and the image has a lower resolution because pixels in the corners of the CCD are not illuminated and therefore not used.

If the designer enlarges the image so that it covers the entire CCD, a square image will result. As Fig. 3.11c illustrates, in this case the full CCD is used, but large portions of the endoscopic image fall outside the photosensitive array and are therefore not captured and not displayed. This wastes the light produced by the endoscope and makes large portions of the peripheral endoscopic field of view unobservable.

A compromise between these two extremes is illustrated in Fig. 3.11d. In this case the objective lens is designed to produce an intermediate-sized image. This allows the CCD to capture most of, but not the entire projected image while minimizing the number of unused pixels at the corners of the CCD. This results in an eight-sided image on the observation monitor. All three of these imaging configurations have been employed by videoendoscope manufacturers.

REPRODUCTION OF COLOR

All solid-state image sensors are inherently monochromatic devices. As monochromatic devices they can produce only a black-and-white image of the mucosa under observation. As Figs. 3.7 and 3.8 illustrate, the silicon photosites employed on the surface of the CCD develop charges in proportion only to the intensity (brightness) of the light falling on the array. The color of the light is not captured and is not known. However, color is extremely important in endoscopic diagnosis and treatment. For an endoscope to reproduce the necessary attribute of color, the imaging system must have some additional means to analyze the color (wavelength) of the light falling on the sensor.

To understand the process of color reproduction, it is helpful to first understand how humans perceive color – because all photographic and electronic imaging systems attempt to mimic the manner in which the human eye and brain respond to color. As Fig. 3.12 illustrates, the sensitivity of the human eye to light varies with the wavelength or color of the light. The human eye is most

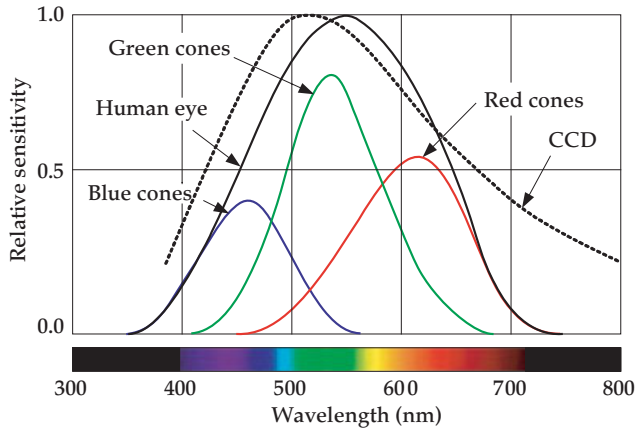

Fig. 3.12 Light sensitivity of CCDs compared to the human eye.

sensitive to green light and less sensitive to reds, blues, and other colors. The CCD has a similar but broader sensitivity, ranging from infrared light (wavelengths > 780 nm), through the visible spectrum, to the ultraviolet spectrum (wavelengths < 380 nm).

Any artist who mixes paints knows that two or more colors mixed together produce a single, newly created color. When observing a mixture of colors, the human eye is nonanalytical and cannot distinguish the original component colors. The perceived hue of this newly created color is determined by a phenomenon that scientists refer to as trichromatic vision.

Trichromatic vision

Nearly any color to which the human eye is sensitive can be simulated by mixing light of only three special colors – red, green, and blue. If three light projectors were fitted with red, green, and blue filters, and the projected light were overlapped, we would obtain an image similar to that shown in Fig. 3.13. The color resulting from the overlap of the red and green projectors

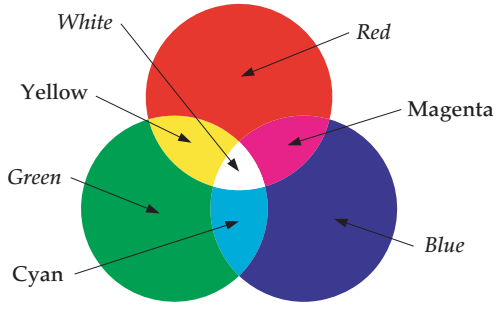

Fig. 3.13 Color theory – additive primary colors.

would be indistinguishable from monochromatic yellow light. Likewise, light from the overlapping green and blue projectors would produce the mental sensation of looking at pure cyan light, and the overlap of red and blue light produces magenta. It is somewhat amazing that where all three of the projectors overlap in the center, the observer will see an area of pure white, with no hint of the three component colors. If the intensities of each of the three projectors were accurately controlled and varied, it would be possible to reproduce essentially any spectral color in the central area of the overlap. It is upon this phenomenon that all video imaging is based.

In the early 1800s, Thomas Young performed such experiments with projectors and was the first to propose the theory that humans possess trichromatic vision. His experiments, and those of his successors, have caused scientists to postulate that humans perceive color through the stimulation of three different types of neural cells (cones) located in the retina of the eye. These cells are presumed to have the approximate sensitivity curves depicted for the red, green, and blue cones illustrated in Fig. 3.12. Since our eyes perceive color based on a trichromatic system, we can trick the eye into seeing full color when looking at a brochure printed using inks of only three colors. A chemist can manufacture color film using only threecolor emulsions. An engineer can design a color video monitor using only red, green, and blue phosphors. In fact, the basis of all color reproduction is tightly linked to the concept of trichromatic vision.

Theory of color video

All video images are reconstructed using the three component colors of red, green, and blue. Because these three colors can be additively combined to mimic all other spectral colors, they are commonly referred to as the *additive primary colors*. It is these three colors, red, green, and blue, that are in fact the phosphor colors used to create the full color images we see on every color video monitor (see Fig. 3.14).

There are currently two very different types of color imaging systems used in commercial video endoscopes. The first commercial video image endoscope system, the VideoEndoscope™ introduced by Welch Allyn in 1983, was based on an RGB sequential imaging system. Many current instruments continue to use this system. The second system, the so-called color-chip endoscope, despite being developed later, has now become the predominant system worldwide. Each color reproduction system has its own advantages and disadvantages, as explained below.

RGB sequential imaging

The components of an RGB sequential video endoscope system are schematically shown in Fig. 3.14. The endoscope has a

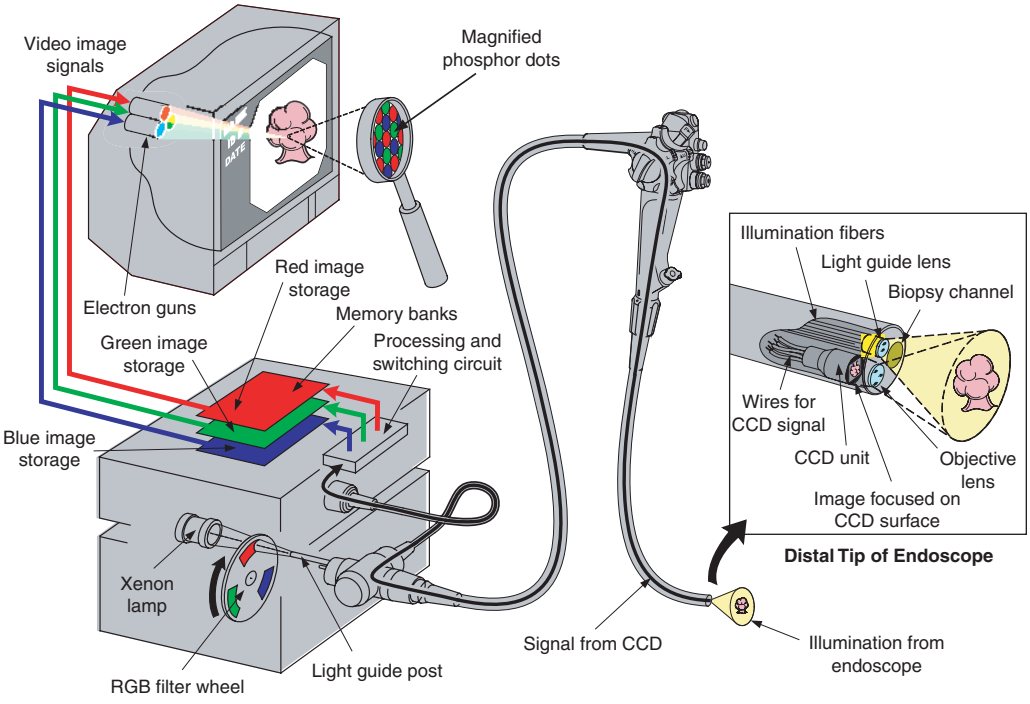

Fig. 3.14 Schematic of an RGB sequential endoscope imaging system.

monochromatic (black-and-white) CCD mounted in its distal tip. The objective lens at the tip of the endoscope focuses a miniature image of endoscope's field of view on the photosensitive surface of this CCD. The endoscope's field of view is illuminated via a fiberoptic bundle that runs through the length of the endoscope, carrying light from a lamp within the light source to the distal tip of the endoscope. Unlike the light used for fiberoptic endoscopes, or the light used for color-chip endoscopes, this light is not continuous, but is strobed or pulsed. It is not only strobed but is also variously colored.

The high-intensity xenon lamp within the light source produces a continuous white light with the approximate color temperature of sunlight. A rotating filter wheel with three colored segments (red, green, and blue) is placed between this lamp and the endoscope's light guide bundle. This filter wheel chops and colors the light falling on the endoscope's light guide bundle into sequential bursts of red, green, and blue illumination. The purpose of this unique illumination system is to produce three separate monochromatic images, each obtained when the field of view is in turn sequentially illuminated by the three primary colors. During the fraction of a second when the red filter is in

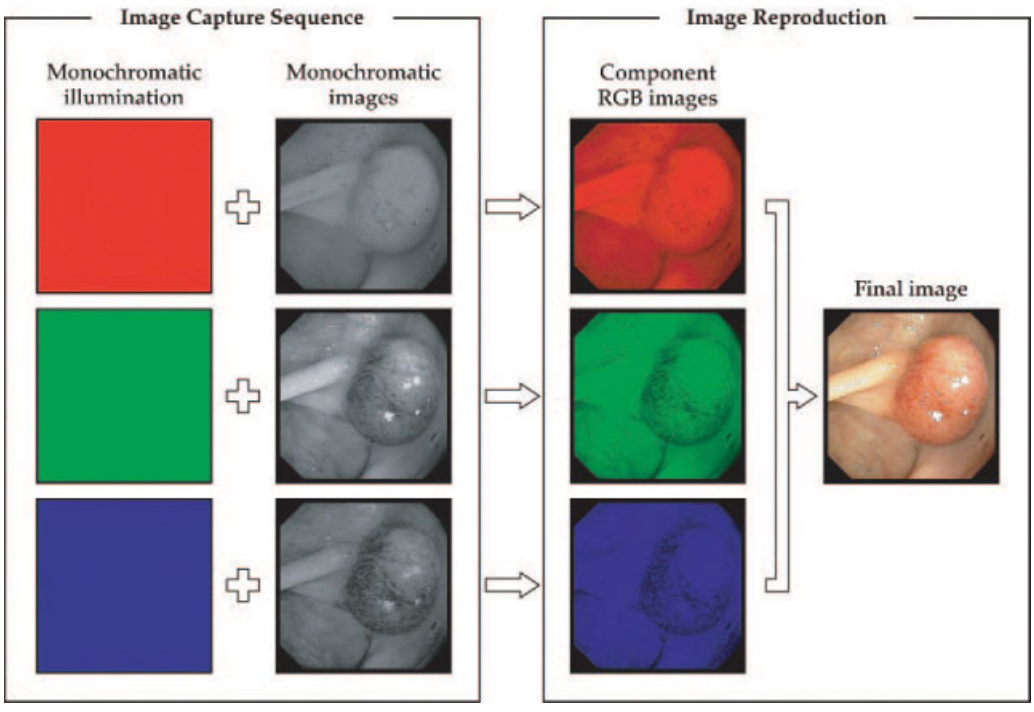

Fig. 3.15 RGB sequential imaging system – the tissue is sequentially illuminated by red, green, and blue light while monochromatic (black and white) images are captured in sequence. These component images are then fed to a video monitor, which generates RGB component images that the observer's eye fuses into a full-color image.

the light path, the GI mucosa is illuminated by red light only. The CCD image sensor instantly captures a monochromatic (black-and-white) image of the mucosa as it appears under this red illumination (see Fig. 3.15). A tissue that is naturally reddish in color reflects heavily under red light and appears to be bright. Areas of the tissue with less red color reflect red light weakly and appear dark under red illumination.

After a monochromatic image of the colon wall is obtained under red illumination, the filter wheel rotates to the adjacent opaque portion of the wheel. At this point the endoscopic illumination goes momentarily dark and the image on the CCD is read out, directed through a processing and switching circuit, and stored in the "red image" memory bank of the video processor (see Fig. 3.14).

After the red image is stored, the filter wheel rotates to place the green filter in the light path. A monochromatic image of the colon wall as it appears under green illumination is then obtained by the CCD (see Fig. 3.15). This image is then read out and sent to the video processor for storage in the "green image" memory bank. In a similar manner, a third monochromatic image

is obtained when the filter wheel rotates to the blue segment; this image is correspondingly stored in the "blue image" memory bank. This sequence of capturing a set of images for each of the three primary colors is repeated 20–30 times each second, the exact rate being determined by the video processor.

Color image display

The steps just described explain the process used to capture images with an RGB sequential imaging endoscope. The technology used to display the resulting image, however, is common to all video systems. The face of the video monitor on which the image is displayed is actually composed of thousands of red, green, and blue phosphor dots, typically arranged in a repeated triangular matrix. The monitor also contains three electron guns, each of which scans over the face of the picture tube in an orderly manner (see Fig. 3.14). The physical design of the "red" gun will allow it to hit and activate only the red phosphor dots. The "green" and "blue" guns are restricted to hitting and illuminating only the green and blue phosphor dots, respectively.

By feeding the signal from the red memory bank of the video processor to the red electron gun in the monitor (see Fig. 3.14), the monitor will reproduce an image of the GI mucosa as it appears under red illumination. This is illustrated by the red component image depicted in Fig. 3.15. Likewise, feeding the images from the green and blue memory banks to the green and blue electron guns, respectively, will reproduce the green and blue components of the original image. (Although three guns are described here, some monitors achieve the same end result using a single electron gun.)

It is a phenomenon of human vision that when two or more sources of color are placed close together, but not overlapping, and are viewed from a sufficient distance, the colors will blend together to form a third color. This third color is the color predicted by the theory of trichromatic vision. This fusion of color sources is referred to as the *juxtaposition of color sources*. Because of this phenomenon, the three intertwined red, green, and blue images on the video monitor appear to fuse together into a single, full-colored, natural-appearing image – rather than remaining a confusing collection of intermixed colored dots. The RGB sequential imaging process just described is summarized in Fig. 3.15.

Color-chip video imaging

A color-chip CCD is essentially a black-and-white image sensor with a custom-fabricated, miniaturized, and multicolored filter bonded to its photosensitive surface. This filter allows the CCD

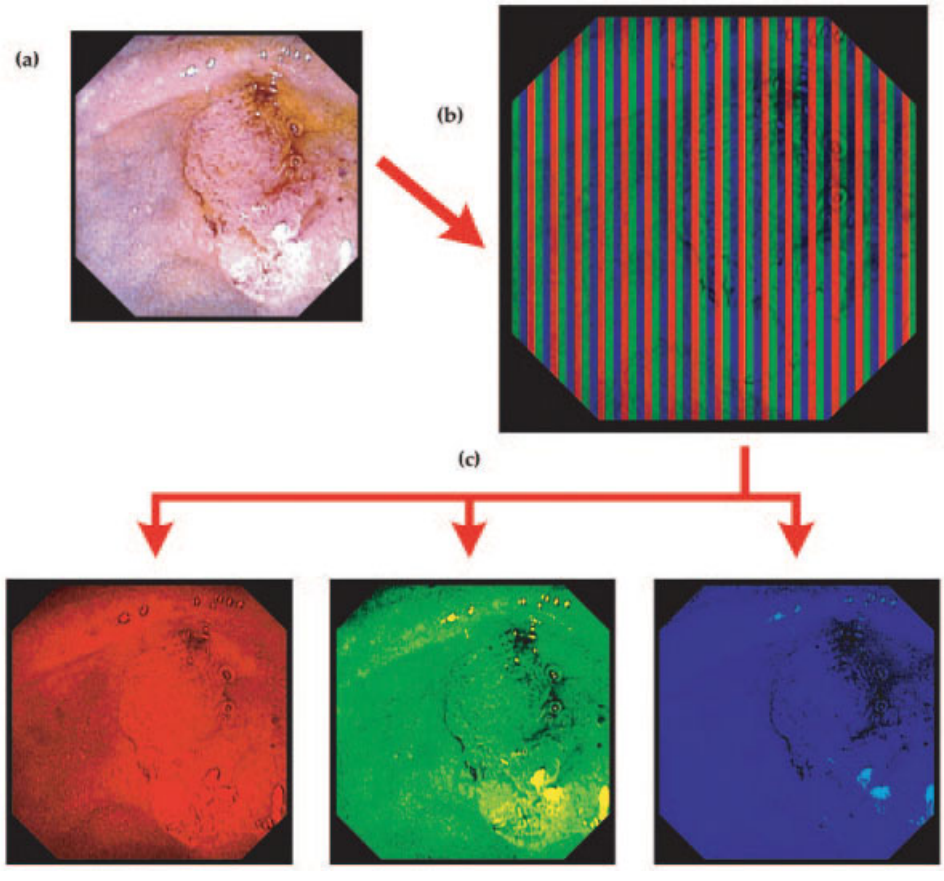

Fig. 3.16 An RGB-striped CCD captures all three color components simultaneously: (a) optical image, (b) image through RGB filter, and (c) RGB component images.

to directly and simultaneously resolve the component colors of the image. The term *instantaneous single-plate CCD* is sometimes employed to emphasize that all three color components are obtained concurrently by a single plate or CCD.

There are a variety of ways to construct a color CCD. One of the simpler methods is to cover the CCD with an RGB-striped filter (see Fig. 3.16). Alternate columns of pixels on the CCD are covered with precisely aligned red, green, and blue strips of filter material. When an image is projected onto the face of such a CCD, pixels behind the red filter segments capture the red component image directly. Likewise, pixels located behind the green and blue filter strips capture the green and blue component images, respectively.

Conceptually the components of the RGB sequential video system (described earlier) and the RGB-striped color-chip system

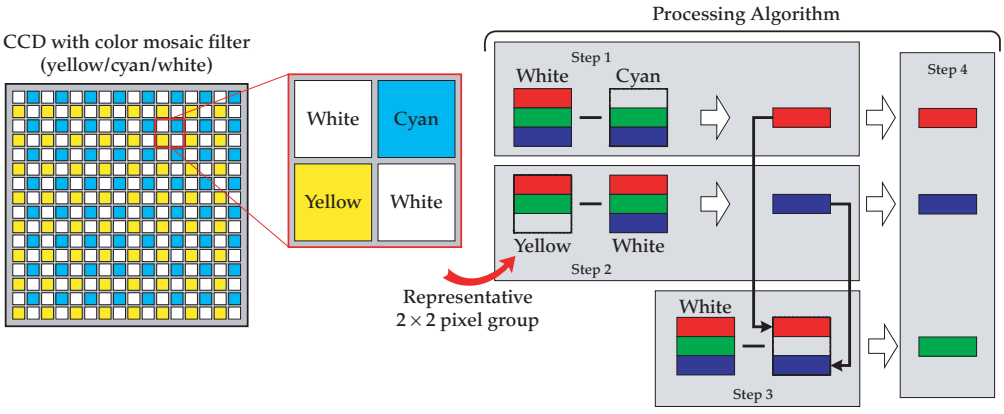

Fig. 3.17 A color mosaic CCD captures light filtered through yellow, cyan, and white filter segments. The resulting image replica is then processed to produce the standard RGB component images.

are the same, except for the fact that the filter segments that were previously mounted on a rotating filter wheel and were placed in the illumination system have now been miniaturized, cut into thin strips, and bonded to the surface of the CCD. Rather than coloring the endoscope's illumination, they now act to filter the image before it hits the photosensitive surface of the CCD.

Although RGB-striped CCDs are easy to understand and are used in other camera applications, they are not commonly used in endoscopes. Endoscopes typically use a color mosaic filter of the type shown in Fig. 3.17. It is possible to design a mosaic filter with a number of different color configurations; however, the color choices and the corresponding algorithm shown in Fig. 3.17 are by far the most common. The colors used in this micro mosaic filter are yellow, cyan, and white (no filter). These segments are arranged in a 2 × 2-pixel box pattern that regularly repeats over the face of the CCD. Since the final output signals to be sent to the observation monitor must be the standard red, green, and blue component images, the image produced behind this yellow/cyan/white filter must first be converted into its primary red, green, and blue components prior to display.

The processing algorithm for doing this is also illustrated in Fig. 3.17. However, to understand this algorithm, it is important to understand how variously colored filters both absorb and transmit light. Figure 3.18 illustrates that, as would be expected, a red filter passes red light but blocks green and blue light. Likewise, a green and a blue filter pass only green and blue light, respectively. A cyan filter blocks only red light, passing both green and blue light. A magenta filter passes both red and blue light, and a yellow filter passes both red and green light. With this background, it is possible to understand the processing

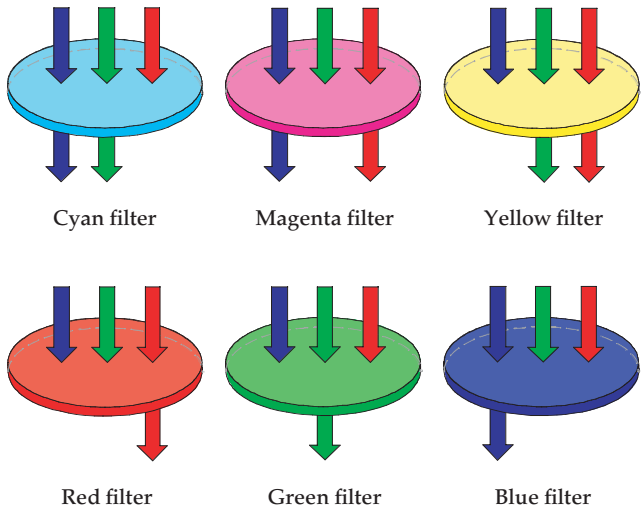

Fig. 3.18 Colored filters selectively separate light into component colors.

algorithm for the yellow/cyan/white mosaic filter typically used in endoscopes and illustrated in Fig. 3.17.

As shown in Step 1, since cyan-filtered pixels received both green and blue light, if we subtract the brightness of this pixel from that of the neighboring white pixel (which receives all light) the difference in brightness would be a measurement of the amount of red light falling on these pixels. In a similar fashion (Step 2), if we subtract the brightness of the yellow pixel that receives both red and green light from that of the neighboring white pixel, the difference in the brightness levels would be an indication of the amount of blue light falling on the pixels. As Step 3 indicates, once the brightness of the red and blue light are known, they can be added together and subtracted from the brightness of a white pixel. This calculation yields the amount of green light falling on the pixels. As a result of this processing it is possible to get the relative component values for the amount of red, green, and blue light falling on the 2×2 yellow/cyan/white filter block (Step 4). This process is then repeated for all 2×2 blocks of pixels across the entire CCD face, thus generating the required RGB components of the original image.

It may be asked why one would go through this extended process if using an RGB-striped filter will yield the RGB component values directly, without calculation. The answer lies in the fact that a yellow/cyan/white mosaic filter has a significant advantage in brightness over an RGB-striped filter. When red, green, and blue filter segments are used, each pixel is filtered to receive only one of the three primary colors. A cyan-filtered pixel, on the

other hand, is exposed to both blue and green light. It is therefore more heavily illuminated than a pure blue or a pure green pixel. Likewise, pixels behind a yellow filter (red and green) or a white filter (no filtration = red + green + blue) receive more photons (light) than pixels behind a pure red, a pure green, or a pure blue filter.

Because of the increased light intensity passing through a yellow/cyan/white mosaic filter, a CCD with this construction exhibits far greater light sensitivity. The improved light sensitivity allows the video endoscope designer to construct an endoscope with a smaller illumination bundle, to maximize the endoscope's angle of view, and to increase the endoscope's depth of field. All of these features improve the instrument's optical performance, but require additional light. Because of this advantage in brightness, all commercial color-chip endoscopes use color mosaic CCDs.

REPRODUCTION OF MOTION

The color-chip video endoscope has an inherent advantage over the RGB sequential endoscope in reproducing motion. The filter wheel in current RGB sequential video processors typically rotates at 20–30 rps. Since each of the color component images are captured individually in sequence, it takes 1/30 s (with a 30-rps filter wheel) to capture the three component images that make up a single video image. If there is any relative motion during this time between the endoscope and the object being viewed, as often occurs during endoscopy, the three component images may differ with respect to object size and position. When these three RGB images are subsequently superimposed on the video monitor, they will be misaligned. This misalignment will be clearly visible if the endoscopist happens to freeze the image while it is moving rapidly. This color separation is present, to a greater or lesser extent, continuously throughout the entire examination. It gives the images an unnatural, highly colorful, and stroboscopic appearance whenever there is rapid motion of the endoscope, the object being viewed, or both. This type of color separation is especially apparent when the endoscopist feeds water to clean the objective lens. The water droplets produce a colorful but distracting flicker across the endoscopic image.

Second generation RGB sequential video processors are engineered to reduce the problem of color separation on captured images. These processors incorporate an anti-color-slip circuit to analyze the video signal in real time and to freeze the image at the moment when color separation is at a minimum (see Barlow 2005). This circuit is remarkably effective in reducing color separation within captured still images. However, this

system does not reduce the strobing, color separation, and water-droplet flicker observed during real-time endoscopy.

The color-chip videoscope, on the other hand, has no problem imaging moving tissue. Because a color-chip endoscope captures all three color components of the image simultaneously, there is never any color separation with either moving or "frozen" images. Since the color-chip endoscope's illumination is continuous and unstrobed, and the frame rate is matched to contemporary TV standards, the reproduction of moving images is always smooth and always appears natural.

Another unique advantage of the color-chip video endoscope is a feature that allows its effective shutter speed to be shortened to increase the sharpness of frozen images. This electronic "fast shutter" feature reduces the blur that may occur if the tissue or endoscope is moving rapidly during the image capture period.

TRANSILLUMINATION

Abdominal transillumination with RGB sequential endoscopes is often problematic since its strobed light output is substantially weaker than that of nonstrobed systems. This weak light is not easily seen through the abdominal wall. Because of this, many RGB sequential light sources have a means for temporarily removing the spinning filter wheel from the light path when placed in the "transillumination" mode. This produces a steady, intense white light that is ideal for transillumination. However, with the filter wheel out of the light path the image is typically lost, since in most cases the illumination is so intense that it saturates the CCD, thus producing a totally white screen. Even if an image is visible, it will be in black-and-white, since the filter wheel must be in its proper position to reproduce color.

LASER THERAPY WITH VIDEO ENDOSCOPES

It is impossible to use a laser that operates within the visible spectrum with a video endoscope. The intense laser light will totally saturate the CCD image sensor, making endoscopic observation impossible. It is, however, possible to adapt video endoscopes for use with lasers that operate outside the visible spectrum. The neodymium/yttrium–aluminum garnet (Nd:YAG) laser produces near-infrared light at 1060 nm. Since the Nd:YAG laser output is outside the visible spectrum, it is possible to make video endoscopes compatible with this commonly used laser by installing a filter over the CCD that transmits visible light (the image) but heavily absorbs the reflected laser light (near-infrared light). Whenever the laser is fired within the endoscopic field, this filter prevents the laser output from reaching the CCD, leaving the image undisturbed.

Both RGB sequential endoscopes and color-chip endoscopes can be outfitted with such a built-in filter, making them compatible with Nd:YAG laser therapy. However, even with such a filter, RGB sequential videoscopes still have problems with Nd:YAG lasers. The first problem is a loss of the true color of the aiming beam. The helium–neon (He–Ne) aiming beam found in almost all Nd:YAG laser systems appears as a red spot when observed with a fiberscope or a color-chip videoscope. However, when observed by an RGB sequential videoscope, the beam appears to be white in color. Because the red aiming beam is on continuously, it appears equally bright to the CCD imager during all portions of the RGB imaging cycle. As a result, the video processor interprets the red He–Ne beam as being white. This bright, artificially white aiming beam will obscure the tissue-blanching effect produced by the Nd:YAG laser itself and thereby impairs observation of the laser's therapeutic effect.

Another disadvantage of the RGB sequential endoscope is the relatively low brightness of its strobed illumination. This causes two problems: (i) the intensity of the laser-aiming beam must be appropriately reduced and (ii) during periods of extended treatment, the tissue may glow at the point of laser impact. Since the burning tissue may be brighter than the videoscope's background illumination, the glowing tissue may cause the CCD to bloom, creating whiteout, which also masks the local tissue effect of the laser.

In contrast, the color-chip videoscope uses intense, nonstrobed white light illumination, similar to that used with fiberscopes. The aiming beam retains its red color, and its intensity is usually not a problem. Because of these factors, the color-chip videoscope is the better choice for endoscopic laser therapy.

IMAGE RESOLUTION

One of the major advantages of the RGB sequential videoscope is the opportunity for increased image resolution. Image resolution is heavily dependent on the number of pixels in the captured image. The physical size of an endoscopic CCD is restricted to the space available within the distal tip of the endoscope. This limits the size of the CCD and the number of pixels that it can contain.

The color-chip system requires information from several different pixels, which is then processed via an algorithm to obtain the red, green, and blue component values for a single point within the image (refer back to Fig. 3.17). In the RGB sequential system, each pixel is illuminated by red, green, and blue light sequentially. Thus, each pixel in turn provides information on each of the three color components. The fact that a single pixel can provide all three color components is an advantage for small

imaging devices like endoscopes. Since the color-chip CCD uses several pixels to provide the same information obtained from a single pixel in the RGB system, the RGB system can theoretically produce the greatest image resolution – based on equivalent numbers of pixels. In practice, this advantage is not significant when designing most video endoscopes, even pediatric instruments, but it is a significant advantage when the thinnest possible endoscope is required (e.g., video choledochoscopy).

COLOR REPRODUCTION ACCURACY

Because the RGB sequential videoscope uses primary-colored filters, and since the color components are isolated, captured, and processed separately within the videoprocessor, this type of videoscope provides very accurate color information. Although both systems produce natural-appearing images, the RGB sequential system can theoretically produce a truer color signal. Again, this potential advantage is not apparent with routine GI endoscopy. The RGB sequential system, however, has the upper hand in image analysis research.

The advantages and disadvantages of the two basic endoscope imaging systems described above are summarized in Table 3.1.

TROUBLESHOOTING

The user manual accompanying your endoscope contains various tips, cautions, and troubleshooting information, which you should become familiar with. Many problems can be corrected instantly, given a little knowledge of how the equipment works. Endoscopes must be handled with care, thoroughly cleaned to remove all debris that could comprise performance (and present an infection control risk), and stored in a protected environment to prevent damage. Routine leak testing is essential to prevent the invasion of fluid into the instrument. Fluid invasion will necessitate extensive and expensive repairs to the instrument.

As endoscopes have become more complex, and have become increasingly integrated with computerized image management systems, the steps required to troubleshoot problems have also become more complex. Table 3.2 contains general troubleshooting information for selected problems. Confirm the details of how to troubleshoot your particular equipment via your manufacturer-supplied user manuals.

ENDOSCOPE REPROCESSING

After each patient exam the endoscope must be reprocessed prior to reuse or storage. The person(s) responsible for reprocessing endoscopes must be thoroughly trained in (i) standard

Feature	RGB sequential video endoscopes	Color-chip video endoscopes
Image resolution	Have a theoretical advantage because each pixel has unique image intensity information. The advantage is primarily seen only in the very smallest of endoscopes.	Have a slight disadvantage because information from multiple pixels must be combined together.
Color accuracy	Have a theoretical advantage because each pixel has unique, directly measured, full-color information. Ideal for research based on spectroscopy and color-analysis algorithms.	Have a slight disadvantage because color is calculated from values of surrounding pixels.
Reproduction of motion	Stroboscopic illumination creates problems with rapid motion. Motion produces color slip and brightly colored artifacts. Newer generation systems have advanced image capture algorithms to reduce the color-slip problem.	Smooth, natural reproduction of motion. No stroboscopic effect. No color artifacts. A fast shutter mode reduces blurring of quickly moving subjects.
Abdominal transillumination	Strobed illumination produces very weak transillumination. ''Transillumination Mode'' results in good transillumination but normal imaging is impossible.	The system's bright, continuous, white light illumination is ideal for transillumination.
Light source compatibility	Requires a special strobing light source.	Videoscopes are compatible with light sources for fiberoptic endoscopes.
Compatibility with laser therapy	The red He–Ne aiming beam appears white and may mask the tissue-blanching effect. Built-in filters enable the endoscope to be used with Nd:YAG lasers.	Built-in filters enable the endoscope to be used with Nd:YAG lasers.

Table 3.1 The advantages and disadvantages of the two basic endoscope imaging systems.

precautions, (ii) Occupational Safety and Health Administration rules on exposure to blood-borne pathogens, (iii) procedures for the safe handling of chemicals, (iv) professional society guidelines (e.g., those promulgated by ASGE, SGNA, APIC, etc.), and (v) the manufacturer's specific procedures for reprocessing the equipment. Reprocessing personnel must also be adequately outfitted with appropriate personal protective equipment for protection against splattering of microorganisms, organic

Problem	Troubleshooting
Poor air or water feeding	(i) Check that the air pump is turned on and set at the proper setting. (ii) Check that the water bottle contains sufficient water, that the lid is screwed on tightly, and that the water bottle tube is connected to the endoscope. NOTE: If the nozzle on the tip of the instrument is obstructed by debris, air and water feeding will be compromised. Thoroughly clean all instrument channels, openings, and nozzles each time the instrument is reprocessed. Some manufacturers supply special adapters for bedside precleaning of the air/water system.
Image is not clear	(i) Feed water and then air to wash debris off distal objective lens. (ii) If permanently obscured, clean the objective lens by carefully rubbing with gauze moistened with alcohol. (iii) Repair the endoscope if the distal lens is damaged or has moisture trapped behind it. NOTE: A cracked or badly scratched lens cannot produce sharp images. Never let the tip of the endoscope contact the floor or other hard surfaces. Protect the distal tip of the endoscope from damage. Moisture trapped behind the lens will cloud the image. Have the endoscope repaired.
Image color is not correct	(i) ''White balance'' the image while pointing the endoscope at a manufacturer-supplied test fixture or a piece of white gauze. (ii) Make sure all color adjustment controls on both the video processor and the video monitor are set in a neutral position. (iii) Check for loose or broken video cables. NOTE: If the endoscope is ''white-balanced'' while pointing at a nonwhite surface, distorted color will result. Many video systems use separate wires for transmitting the red, green, and blue component images. If one of these wires is disconnected or broken, the color of the image on the monitor will be severely distorted.
Image is permanently frozen or completely absent	(i) Turn off and on again both the light source and the video processor. This may correct the problem if it is microprocessor related. (ii) Check all wires for accidental disconnection. (iii) Check the input selector on the video monitor to ensure that it is set to display the input with the endoscopic image. (iv) Press the ''Reset'' button on the video processor, if one is available. This will return the videoprocessor settings back to their factory defaults. (e.g., if the video processor was accidentally set to display an image from the image management software or a VCR, rather than from the endoscope, pressing Reset will restore the live endoscopic image.)
The image cannot be restored and the endoscope must be withdrawn from the patient	(i) Close and remove all accessories from the endoscope channel. (ii) If using a colonoscope with adjustable stiffness, set the stiffness control to the ''most flexible'' setting. (iii) Make sure that the angulation locks are off. (iv) Return both angulation knobs to their neutral position in order to straighten the distal tip. (v) Carefully withdraw the endoscope. NOTE: If the endoscope cannot be withdrawn easily, stop and contact the endoscope manufacturer's service center for additional instructions.
The endoscope is damaged	If the endoscope insertion tube is damaged by a patient bite, by accidental closure in the carrying case hinge, or by other means, do not continue to use the endoscope. Futher use of the endoscope could cause additional damage to internal components of the instrument, adding to the repair cost.

Table 3.2 General troubleshooting information for selective problems.

matter, and reprocessing chemicals. Adequate personal protective equipment includes (i) long-sleeved gowns that are impervious to fluid, (ii) gloves that are long enough to extend up the arms to protect the forearms, and (iii) eye and/or face protection.

Cleaning

Following patient use, the endoscope should be immediately precleaned at the bedside by flushing the internal channels and wiping down the insertion tube. Following bedside precleaning, the endoscope is brought to the reprocessing room for manual cleaning. Thorough manual cleaning is often described as being "the most important step" of the entire reprocessing procedure. Cleaning removes gross debris and organic matter that can dry on the instrumentation and hinder future performance (e.g., flow through the air/water nozzle). Studies have shown that cleaning alone can reduce the number of microorganisms and organic load on the instrument by 4 logs, or 99.99%. This significantly reduces the organic and microbial challenge to the high-level disinfectant or sterilant. Furthermore, residual debris may inhibit germicide penetration and shield microorganisms from contact with the germicide. The recommended channel-cleaning brushes and any special brushes (e.g., channel-opening-cleaning brush) supplied by the manufacturer must be used to mechanically abrade all lumens while they are wetted with detergent. After manual cleaning is complete, there should be no visible debris left on the instrument.

When cleaning and disinfecting the endoscope, the cleaning tubes and attachments recommended by the endoscope manufacturer for flushing the internal lumens of the endoscope must be used. This ensures that the required volume of fluid for cleaning, disinfection/sterilization, and rinsing passes through the internal channels. Figure 3.19 illustrates one such manufacturer's range of cleaning attachments. The Food and Drug Administration (FDA) requires that the endoscope manufacturer validate the steps listed in each instrument's instruction manual. These instructions must be followed explicitly. Shortcutting the prescribed procedure may result in an inadequately reprocessed instrument that presents an infection control risk to medical personnel and the next patient.

Leak testing

Periodically performing a leak test is an essential part of the reprocessing procedure. Leak testing the endoscope ensures that the seals, lumens, and external surface of the endoscope are fluid tight and will not allow reprocessing fluids to enter the interior of the endoscope. If a leak if detected, have the endoscope

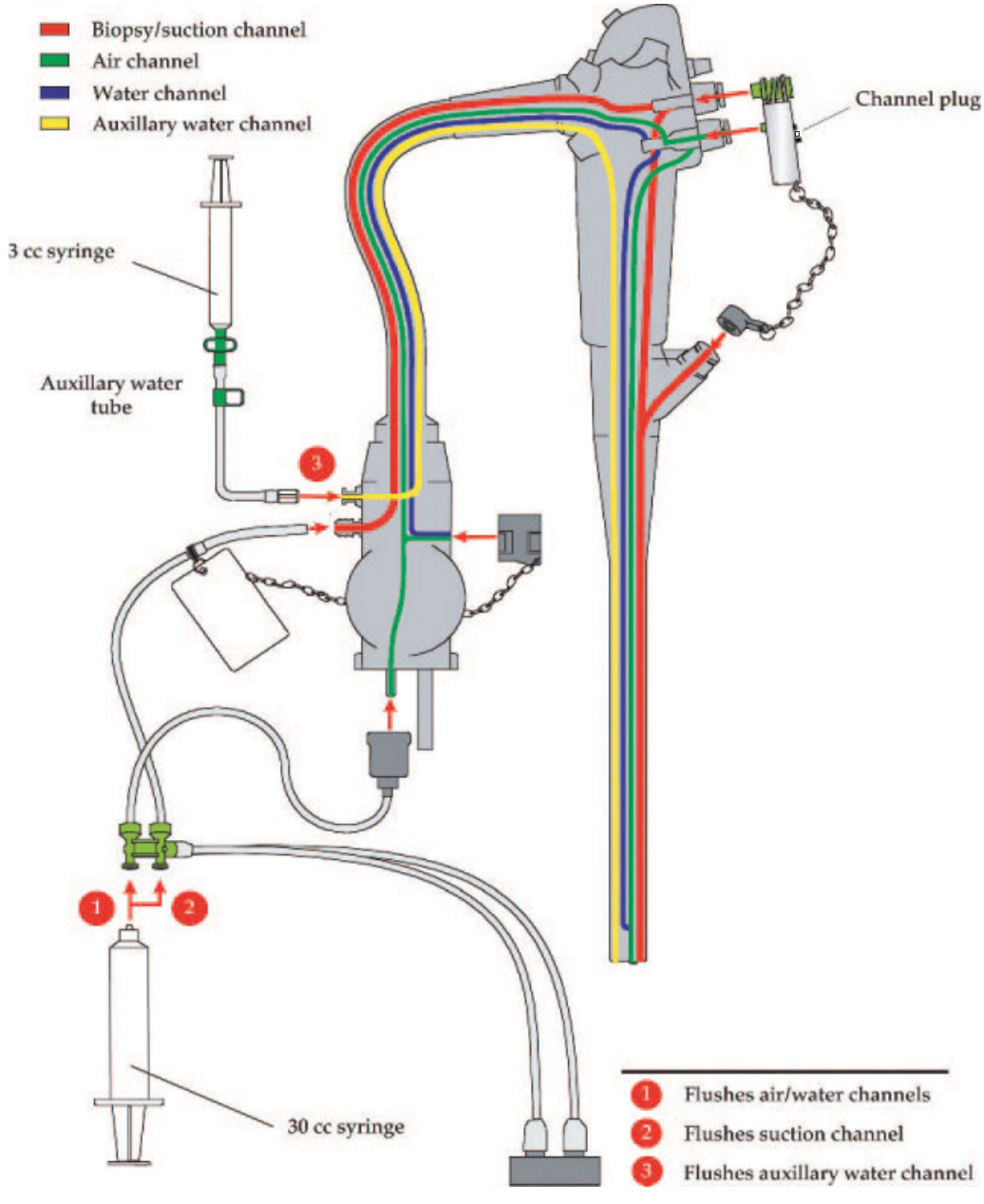

Fig. 3.19 The cleaning attachments required to flush reprocessing chemicals through the lumens of a typical Olympus 160/180-series video endoscope.

repaired immediately. Fluid invasion of the endoscope can cause extensive and expensive damage. Furthermore, a breach in the surface integrity of the endoscope can allow microorganisms to enter the endoscope body, where they can reside and later emerge, creating an infection control risk. For all these reasons, every endoscope should be leak tested on a regular basis. During leak testing, and any time the endoscope is submerged in fluid, it is important that all sensitive components be protected from fluid contact. Most endoscopes require the attachment of a water-resistant cap to the electrical connector of the endoscope. This cap must remain attached during the entire reprocessing procedure.

High-level disinfection

In 1968, Dr Earle H. Spaulding devised a classification system that divided medical devices into three categories (critical, semicritical, and noncritical) based on the risk of infection involved with their use. Based on the Spaulding classification system, GI endoscopes are considered by the FDA to be "semicritical medical devices". Semicritical medical devices are instruments that do not enter sterile areas of the body and are generally in contact with intact mucous membranes. As such, both high-level disinfection and sterilization are acceptable methods for reprocessing GI endoscopes.

High-level disinfection via an approved liquid chemical germicide is the most commonly used method for reprocessing GI endoscopes. High-level disinfection destroys all vegetative organisms, but not necessarily all bacterial endospores. The germicide must be cleared by the FDA explicitly as a high-level disinfectant. The FDA has approved several high-level disinfectants for use on medical devices, including 2.0–3.4% glutaraldehydes, 7.5% hydrogen peroxide, 0.2% peracetic acid, 0.08% peracetic acid/1% hydrogen peroxide, and 0.55% ortho-phthalaldehyde. Each of these germicides has advantages and disadvantages in terms of cost, contact time, temperature, and fume control requirements. However, it is important to note that not all of these products are compatible with all endoscopes. Always check with the endoscope manufacturer regarding chemical compatibility.

Endoscopes are composed of a variety of rubbers, plastics, metals, glasses, adhesives, coatings, etc., which may be either immediately damaged or gradually deteriorated following long-term exposure to certain chemicals. Reported damage from incompatible chemical germicides includes the loss of exterior body surface color and/or luster, loss of insertion tube stiffness, peeling of the insertion tube coating material, pitting and corrosion of anodized aluminum parts, chipping and peeling of painted and coated parts, crazing of plastic parts, deterioration

of adhesives, and insertion tubes that become sticky to the touch. The damage produced by some chemicals is quickly apparent. However, other chemicals may initially appear to be compatible, with cumulative effects that only become apparent following extended use of the germicide. The compatibility of all reprocessing chemicals should be determined by contacting the endoscope manufacturer. If a third-party repair organization services the endoscope, check with the service provider regarding the chemical compatibility of replacement parts.

Some germicides are suitable for manual reprocessing at room temperature. Others require heating and are only approved for use in automated reprocessors. Glutaraldehydes have been used for 30 years and are available in both room temperature and heated formulations. They are relatively inexpensive, but may require fume control in accordance with local and state regulations. Glutaraldehyde is an irritant and some individuals develop acute sensitivities resulting in irritation to the skin, eyes, and nasal membranes, headaches, coughing, sneezing, and asthma-like symptoms. The safe use of glutaraldehydes requires adequate ventilation (e.g., exhaust hoods, ductless absorbent filter systems) or enclosed automated reprocessing systems.

The efficacy of any chemical germicide is dependent upon the manufacturer's instructions for use. The label instructions regarding activation (if required), reuse life, and shelf life must be followed explicitly. All reusable germicides should be tested regularly, as recommended by the manufacturer, to ensure that they exceed the minimum effective concentration of the active ingredient. The addition of significant quantities of microbes and organic matter, dilution by rinse water, and aging of the chemical solution, will all result in a gradual reduction in the effectiveness of reusable high-level disinfectants/sterilants.

Alcohol flush

Although many automated reprocessors use 0.2-μm microbial retention filters to produce "sterile" water for the final rinse following disinfection, other endoscopy units rinse their endoscopes in tap water. Irrespective of the quality of the final water rinse ("tap" water, "bacteria-free" water, "sterile" water), the entire endoscope should be dried and each of its channels flushed with 70% alcohol, followed by an air purge prior to reuse or storage. Alcohol aids in the drying process and inhibits the recontamination of the internal channels with water-borne organisms.

Special channels

Some endoscopes have special channels, such as an auxiliary water or water-jet channel. These channels must be fully

reprocessed after each patient use, regardless of whether the channel was used during the preceding patient examination. Patient debris and microorganisms can enter these channels even if they are not used during the endoscopy exam. These channels often require additional steps and special attachments to access and flush the channel with detergent, disinfectant, rinse water, and alcohol (see Fig. 3.19).

Automated reprocessors

Automated reprocessors standardize the disinfection process and decrease personnel exposure to high-level disinfectants/sterilants. No currently available reprocessor is approved for automating the entire cleaning procedure. As a result, all of the prescribed steps for manually cleaning the endoscope must be performed prior to placing it in the automated reprocessor. If an automated endoscope reprocessor is used, the endoscope must be connected to the reprocessor using the correct set of connecting tubes. Some endoscope models, particularly those with special channels, may require a different set of connecting tubes from those used on standard instruments. Failing to connect a specific channel opening or port to the reprocessor may result in patient debris and infectious material remaining in the channel. Failure to reprocess any part of the endoscope poses an infection control risk to both medical personnel and patients.

Rinsing and disposal

Whether reprocessing manually or using an automated machine, all disinfectant must be flushed from the endoscope's internal lumens during the rinse process. There have been several reports in the medical literature of patients enduring chemical burns and/or chemical colitis when residual disinfectant solution was expelled from the endoscope's channels when used on the following patient.

Some germicides require deactivation or dilution prior to disposal. State or local ordinances may prohibit the dumping or disposal of certain germicides into the city waste water system. Check with the germicide manufacturer and with state and local authorities regarding disposal requirements.

Accessories

Many endoscopic accessories are deemed to be "critical" medical devices by the Spaulding classification system, since they either penetrate mucous membranes (e.g., endoscopic cutting devices) or enter normally sterile areas of the body (e.g., biliary ducts). As such, they should be sterilized prior to reuse. Steam sterilization

is the preferred method of sterilizing any reusable endoscopic accessory that is autoclavable. After sterilization, store sterile accessories in an organized and protected storage system that prevents damage to the sterile packaging.

Storage

Store reprocessed endoscopes in a well-ventilated storage area where they are protected against damage and contamination. Endoscopes should be stored with all valves and removable parts removed, to facilitate drying. The endoscope-carrying case should never be used for storage of patient-ready endoscopes. Carrying cases are not ventilated, easily contaminated, cannot be reprocessed, and intended for shipping and long-term storage only. Never put an endoscope that has not been completely reprocessed into its carrying case. In addition, reprocess any endoscope that is removed from a carrying case prior to subsequent patient use.

SUMMARY

During the 1990s, video image endoscopes supplanted fiberoptic endoscopes as the preferred instrument for examining the GI tract. The availability of two distinct technologies for generating color images (color-chip versus RGB sequential) provides the endoscopist with a choice of basic systems, each with its own advantages and disadvantages. Although the basic shape and function of the instrument have remained unchanged, recent advancements – including the development of smaller diameter insertion tubes, the incorporation of standard features into pediatric instruments, improvements in image resolution, and advanced video processor features – have continued the evolution of the GI endoscope. Proper reprocessing equipment and procedures and a trained reprocessing staff are essential to ensuring the health and safety of health care workers and patients alike.

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Practical Pediatric Gastrointestinal Endoscopy
George Gershman, Marvin Ament

Patient Preparation

4

The patient preparation before pediatric gastrointestinal endoscopies targets anxiety reduction, reassurance of child well-being, and creation of the optimal conditions for safe sedation and monitoring during procedure and recovery. A high level of anxiety is typical for children and parents before endoscopy. This has to be reduced as much as possible to minimize a child's stress and parental frustration and to create a suitable condition for the patient–nurse interaction during placement of the intravenous access, obtaining baseline vital signs, and placement of the monitoring sensors. It is extremely important to find a delicate balance between the full disclosure of the invasive nature of the procedure and related complications and anticipated parental and patient responses to the disclosed information. This is one of the moments when a pediatric gastroenterologist should act as a well-trained psychologist for the parents and the patient because parental cooperation and support is an important element of patient preparation. The preprocedure conversation emphasizes the fact that the routine endoscopic procedure is safe and is going to be performed by a very well trained physician and assistants in the medical facility, which is fully equipped for any supportive care necessary.

The assessment of the patient is focused on the child well-being and recognition of any risk factors, such as recent meals, allergies, recent respiratory illness, or chronic conditions, such as asthma, gastroesophageal reflux disease, seizure disorder, or other diseases, which may complicate a sedation or the patient's recovery. Children with the American Society of Anesthesiologists (ASA) physical status 3 and 4 and patients who are going to have procedures such as achalasia dilation, foreign body removal, and percutaneous endoscopic gastrostomy placement are typically selected for general anesthesia and should be assessed by an anesthesiologist. Children with congenital heart diseases or a compromised immune system are candidates for endocorditis prophylaxis. The intravenous access should be established and secured by well-trained medical personnel. Special attention has to be paid to the right size and placement of the pulse oximeter sensors because detachment from the skin, displacement of the two diodes more than 2–3 mm, or exposure to ambient light may lead to an optical shunt and false high or low readings. Parental cooperation and support is also an important element of the patient's preparation.

PEDIATRIC-MONITORED SEDATION AND ANESTHESIA FOR DIAGNOSTIC AND THERAPEUTIC PROCEDURES IN ENDOSCOPY

Monitored sedation and analgesia for diagnostic and therapeutic procedures performed by pediatric gastroenterologists and anesthesiologists outside of the operating room has dramatically increased. In the recent past there has been a great understanding on how to perform sedation and analgesia in infants and children within and outside the operating room in ways that minimize their potential fear or pain.

Endoscopic procedures performed outside of the operating room require the same attention to anxiolysis, analgesia, and sedation as procedures performed in the operating room.

Painful procedures such as endoscopy and liver biopsy require analgesia and often monitored sedation. The sedation which is usually provided may reach levels that are quite deep or be similar to general anesthesia.

Young children as well as those that are developmentally and mentally handicapped are often unable to remain motionless for even short periods of time. This is not all that different in children without these disabilities. The fear and anxiety, which is often associated with the contemplation of procedures, is at times difficult to control and may be worsened by parental anxiety, separation from the parents, and the anticipation of potential pain from the procedure.

One of the major reasons for the increase in procedures outside of the operating room that require monitored sedation and analgesia has been the emphasis by managed care providers on lowering cost.

Third care providers and managed care providers have the belief that performing these procedures outside of the operating room will lower cost. It is assumed that monitored sedation and analgesia for diagnostic and therapeutic procedures can be provided more cheaply, conveniently, and efficiently outside of the operating room.

In many instances endoscopic procedures, which in the past may have been performed in the operating or recovery room, are now performed in offices or special procedure rooms, at times without the direct supervision of an anesthesiologist.

Anesthesiologists have helped to develop institution guidelines for monitored sedation as well as anesthesia outside of the operating room as required by the Joint Commission on Accreditation of Healthcare Organizations.

Definition of levels of sedation

Sedation and analgesia for diagnostic procedures such as upper intestinal endoscopy and colonoscopy represents a continuum of consciousness to unconsciousness, with three levels more

commonly described: conscious sedation, deep sedation, and general anesthesia. Sedation and analgesia for procedures is a continuum; a patient may easily pass from a light level of sedation to general anesthesia. The American Academy of Pediatrics (AAP) formalized and defined the concepts of conscious sedation, deep sedation, and general anesthesia as follows: *conscious sedation* is defined as a medically controlled state of depressed consciousness that allows protected reflexes to be maintained, retains the ability to maintain a patent airway independently and continuously, and permits appropriate responses by the patient to physical stimulation or verbal commands; for example, "open your eyes."

Deep sedation is defined as a medically controlled state of depressed consciousness or unconsciousness from which the patient is not easily aroused. It may be accompanied by a partial or complete loss of protective reflexes, and includes the inability to maintain a patent airway independently and respond purposefully to physical stimulation of verbal command.

General anesthesia is defined as a medically controlled state of unconsciousness accompanied by a loss of protective reflexes, including the inability to maintain an airway independently and respond purposefully to physical stimulation of verbal command.

A common problem with assessing a sedated child is the difficulty of interpreting any movement in response to pain as "appropriate" and therefore a sign of "conscious sedation." An infant or a child who is consciously sedated should respond to pain by saying "ouch," pushing your hand away and/or pulling the covers over himself or herself. Reflex withdrawal from pain is considered a sign of deep sedation and not conscious sedation and should lead to escalation of care of the patient since respiratory depression may occur.

Most procedures in children requiring sedation can be done only during deep sedation. The ability to achieve a state of anxiolysis and immobility during a painful or frightening procedure in small children using conscious sedation is extremely difficult. Small children can very easily move from conscious to deep sedation with loss of airway reflexes. It should be assumed that children younger than 6 years will require a greater level of vigilance than that required for deep sedation. We believe that it is virtually impossible to do conscious sedation in children younger than 6 years.

Goals of sedation

What are the goals of pediatric sedation? They can be summarized as follows:

1 Guard the patient's safety and welfare
2 Minimize physical discomfort or pain

3 Minimize negative psychological responses to treatment by providing analgesia and anxiolysis and maximize the potential for amnesia
4 Control behavior
5 Return the patient to a state in which safe discharge is possible

Risks and complications associated with monitored sedation

The goal is always to optimize patient safety by minimizing complications. There are many case reports describing pediatric sedation complications but limited hard data of the frequency of adverse effects compared to the total number of sedations. Risk equals the number of adverse events over the number of patients sedated. The number of reported cases of adverse outcome we believe is only a small number of those that occur. There are no really good studies that look at true risk factors, considering age of the patient, underlying disease, level of sedation, type of drug, monitors, personnel, guidelines used for sedation, severity of the event, and experience and type of practitioner.

In a very large dental study involving 3000 dentists, 74% of adverse reactions did not require hospitalizations, whereas 26% required intubation and life support. The overall incidence of adverse effects was 1 in 5000 where narcotics were administered and 1 in 20,000 sedated with nonnarcotics. Death and morbidity was said to be 1 in 10,000 where narcotics were administered and less when nonnarcotics were administered.

Limited numbers of pediatric studies look at the risk involved in doing endoscopy. Carefully collected data on adverse pediatric outcomes in pediatric upper intestinal and lower intestinal endoscopy are not available. In a large study reported in *Pediatrics* in 2000, Cote and others reported on the adverse sedation events in pediatrics. This was a critical incident analysis of contributory factors. The primary event in both the hospital-based and non-hospital-based patients was respiratory, the secondary event was cardiac arrest, and the third was inadequate resuscitation. The outcome in these adverse events included 37% who died in the hospital-based series and 92% in the non-hospital-based series. Some of the other causes of adverse sedation events included drug–drug interactions, inadequate monitoring, inadequate medical evaluation, lack of an independent observer, and inadequate management of resuscitation. Successful outcome was related to the use of pulse oximetry in patients compared to those without any monitoring. Seventy-eight percent of adverse outcomes in patients who were not monitored resulted in death or neurologic injury, whereas 24% of patients who were monitored with pulse oximetry

died or had neurologic injury. All patients monitored with pulse oximetry in hospital-based venue were rescued without injury.

The following conclusions were determined from this study:
1 All classes of drugs (sedatives, barbituates, benzodiazepans, and narcotics) have been associated with problems even when administered in "recommended doses."
2 All areas using sedation have reported adverse events.
3 Children 1–6 years of age are at greatest risk. Most had no severe underlying disease.
4 Respiratory depression, airway obstruction, desaturation, and apnea are the most frequently encountered adverse effects.
5 Adverse events involved multiple drugs, drug errors or overdose, inadequate medical evaluation, inadequate monitoring, inadequate practitioner skills, and premature discharge.
6 Most complications from sedation were avoidable.
7 Uniform guidelines for both in hospital and out of hospital sedation must include appropriate personnel skilled in airway management and resuscitation.
8 Health care personnel who sedate children for procedures must have advanced airway and resuscitation skills so as to successfully manage complications and rescue the patient.

The AAP guidelines are divided into "before sedation," "during sedation," and "postsedation" categories. Pediatric gastroenterologists and anesthesiologists should use these guidelines as a template for their own institutional guidelines.

Before sedation

Facilities, personnel, and equipment must be immediately available to treat emergency situations arising from sedation. These complications include vomiting, aspiration, seizures, anaphylaxis, respiratory depression, airway obstruction, apnea, and cardiac arrest. A protocol for backup emergency services shall be clearly identified. In nonhospital environments, ambulance services must be assured. On-site equipment of appropriate sizes must be immediately available and must include the following: (i) positive pressure O_2 delivery system (90% O_2 for greater than or equal to 60 min; check before each sedation); (ii) suction and catheters; (iii) noninvasive blood pressure measurement equipment; (iv) pulse oximetry; and (v) emergency cart with age- and size-appropriate drugs and equipment.

Sedatives should not be administered at home or in a facility unsupervised by medically trained personnel, since unrecognized complications may lead to disaster. Sedatives should be administered only by appropriately trained health care providers and only in a facility where appropriate monitoring and personnel are available.

Documentation before sedation must include the following:

1 Informed consent in accordance with local, state, and institutional guidelines.

2 Verbal and written instructions to the responsible person. These shall include the objectives of sedation, anticipated changes in behavior, discharge instructions, and a 24-hour telephone number for follow-up.

3 Dietary precautions must be clearly stated and documented for elective sedation. Elective patients at risk for aspiration, for example, uncontrolled gastroesophageal reflux and obesity, may benefit from drugs to decrease gastric volume and/or acidity. In emergency situations in which appropriate NPO (nil per os) status cannot be established, the lightest effective level of sedation should be used. An emergency patient may require intubation to protect the airway before sedation.

4 A health evaluation must be performed either by the patient's practitioner or by the gastroenterologist before the procedure. The evaluation must include the following: (i) age and weight of patient; (ii) health history: allergies, drug usage, relevant diseases, physical abnormalities, history of sedation or general anesthesia, relevant family history; (iii) reviews of systems: especially note airway problems, for example, loud snoring and obstructive sleep apnea, recent colds, croup, poorly controlled asthma, unexplained cyanosis, central nervous system's abnormalities, and seizure history; (iv) physical examination, especially a focused airway examination, looking for anatomic airway abnormalities, such as large tonsils, hypoplastic mandible, midfacial hypoplasia, and cervical spine abnormalities; (v) vital signs, heart rate, blood pressure, respiratory rate, and temperature; (vi) ASA physical status classification.

A detailed health evaluation is critical in identifying children whose underlying medical conditions may place them at increased risk for sedation complications. Patients such as these should be referred to an anesthesiologist or other qualified specialist for sedation. We are particularly concerned if a patient has upper airway obstruction that would likely become worse with the administration of sedatives. Tonsils and adenoid hypertrophy, which are common in children, are often associated with loud snoring or obstructive sleep apnea. Parents will frequently tell the practitioner if their child snores loudly and then "stops breathing." These children are at increased risk for airway obstruction and should be referred to an airway specialist for procedures requiring any sedation.

Problems for which consultation with an anesthesiologist is suggested are as follows:

1 *Medical problems*:

(a) ASA class 3 or 4 status

(b) Pulmonary airway obstruction (tonsils/adenoids): loud snoring, obstructive sleep apnea, poorly controlled asthma
(c) Morbid obesity greater than or equal to two times ideal body weight
(d) Cardiovascular condition such as cyanosis and congestive heart failure

2 *Prematurity less than 60 weeks of postconceptual age*: residual pulmonary, cardiovascular, gastrointestinal, and neurologic problems

3 *Neurologic conditions*: poorly controlled seizures, central apnea

4 *Gastrointestinal conditions*: uncontrolled gastroesophageal reflux, procedures required during sedation in patients with a full stomach, management problems (severe developmental delay, patients who are difficult to control, history of failed sedation, oversedation, hyperactive [perodoxical response to sedatives])

The physician must review the child's presedation medications to determine if any are being used that will affect the sedation. Patients who are on protease inhibitors for treatment of human immunodeficiency virus should recognize that they are potent inhibitors of the cytochrome P450 metabolic pathway. This pathway is responsible for the metabolism of many sedatives, including menazolam, and may markedly prolong its duration of action and may lead to life-threatening respiratory depression.

DURING SEDATION

The AAP guidelines require a minimum of two persons during sedation. We believe no less than three should be present for any endoscopic procedure in a pediatric patient. There must be a nurse to assist the physician in doing the endoscopic procedure and to assist in taking biopsy specimens and mounting them. The third individual should be paying attention and recording vital signs of the patient and should provide additional medication as may be necessary as dictated by the endoscopist.

The gastroenterologist must be competent in using and administering sedatives, providing appropriate monitoring, and managing complications. Training in pediatric basic life support is required. Pediatric advanced life support is strongly recommended.

The third individual we feel should be responsible for doing the monitoring and assisting in supportive care and resuscitation if this becomes necessary. We believe this assistance should have pediatric basic life support training. If the infant or child becomes deeply sedated, one person must have as his or her responsibility the role of constantly observing the patient's vital signs, airway patency, and adequacy of ventilation.

Documentation should occur on a time-based "sedation flow chart" similar to an "anesthesia record." The sedation flow chart should be uniform throughout the institution and designed to be easy to use, complete, and comprehensive such that while filling out the form all aspects of the AAP guidelines are followed. This includes presedation and postsedation sections. The flow chart should have guideline instructions on the back, which answer questions that are commonly asked during the sedation process.

Baseline vital signs shall be documented on the sedation flow chart. The name, route, time of administration, and dosage of all drugs administered must be recorded. There must be continuous quantitative monitoring of oxygen saturation and heart rate, such as by pulse oximetry. The time-based sedation flow chart must contain intermittent recording of respiratory rate, heart rate, oxygen saturation, and blood pressure as well as the level of consciousness and responsiveness.

The typical time interval for recording data during the sedation is every 15 minutes unless this interferes with the procedure. If the child becomes deeply sedated then vital signs must be documented every 5 minutes.

POSTSEDATION CARE

The child must recover in a facility with adequate cardiorespiratory monitering, oxygen delivery system and a functioning suction apparatus. The patient's vital signs should be recorded at specific intervals. Recording usually occurs every 15 minutes unless the child is deeply sedated, in which case vital signs should be recorded every 5 minutes. Recommended discharge criteria include the following:

1 Cardiovascular function and airway patency are stable and satisfactory.
2 The child is easily aroused and protective reflexes are intact.
3 Patient can speak if age-appropriate.
4 Patient can sit up if age-appropriate or walk with assistance.
5 Presedation level of consciousness is achieved or is as close as possible to normal level for very young or handicapped children.
6 Adequate state of hydration exists.

SPECIFIC SEDATION TECHNIQUES

Sedation treatment plan should be considered before the procedures to be undertaken. The physician needs to think about the requirements for analgesics, anxiolytics, or both. Depending on the procedure and the anxiety of the patient and the family, the needs may vary from child to child. Psychological techniques are sometimes useful to put their anxiety to rest. These can include

cuddling of the patient, parental support, warm blankets, a gentle reassuring voice, and rarely hypnosis.

The main classes of drugs used for sedation analgesia for diagnostic and therapeutic procedures are as follows:

1 Local anesthetics
2 Anxiolytics and sedatives
3 Barbituates
4 Opiod analgesics
5 Systemic anesthetics

Topical administration of local anesthetics is useful in the sedated patient. Before an intravenous line is to be placed, the EMLA cream should be applied on the skin where the intravenous infusion device is to be placed about 60 minutes beforehand. Usually two sites should be chosen in case the physician has difficulty with accessing the intravenous site. Ideally the patient should arrive 1–1.5 hours before the procedure to check in and to have the EMLA cream applied on the skin. This is extremely useful in reducing the pain of venipuncture.

EMLA cream is a mixture of lidocaine 2.5% and prilocaine 2.5%. The effect of the EMLA cream lasts 1–2 hours after it is removed. Adverse effects of EMLA cream include skin blanching, erythema, itching, rashes, and rarely methemoglobinemia. It is been contraindicated in children younger than 1 month or those who are known to have congenital or idiopathic methemoglobinemia. It has also been proscribed in those receiving phenytoin, phenobarbital, acetaminophen, and sulfonamides.

The benzodiazepines (diazepam and midazolam) are among the most commonly used sedatives in pediatric practice. They exert their effects by interacting with γ-aminobutyric acid receptors in the central nervous system. The sedated child usually becomes compliant but does not lose consciousness with these agents. Children frequently move and another agent such as a narcotic is necessary if the patient must not move for the procedure to be successfully accomplished. Many children initially act disinhibited following small doses of benzodiazepan; some patients may have a paradoxical response and become more agitated with higher doses. It is wise to change to a different sedative drug in such patients since increasing the dose of benzodiazepan may lead to severe agitation followed by unconsciousness and respiratory compromise. The benzodiazepans have the advantage of antigrade amnesia in a significant number of patients. Benzodiazepans produce mild respiratory depression and upper airway obstruction. This depression may become severe in compromised patients or in children with tonsillar hypertrophy. The combination of benzodiazepans and narcotics can produce a superadditive effect on respiratory depression in which the total depressant effect from the combination of drugs is much greater than the sum of their anticipated individual effects. Diazepam is

more fat-soluble than midazolam and has twice the duration of sedative effect, but intravenous administration can be painful. The onset of intravenous diazepam is approximately three times faster than that of intravenous midazolam, whereas the onset of oral midazolam is faster than that of oral diazepam. The markedly prolonged and variable elimination half-life and active metabolite of diazepam make midazolam a superior sedative drug in children, particularly in infants. Midazolam is the only drug in this class approved for neonates. It can be given intravenously, intranasally, sublingually, orally, or rectally. It can be given through many routes but in many instances the oral route is the preferred one. An oral cherry-flavored form is now available. Nasal burning occurs when it is administered transnasally. Rectal administration has been used but absorption may be irregular owing to many factors.

Flumazenil is a specific benzodiazepan antagonist and will rapidly reverse the sedative and respiratory effects of benzodiazepans.

In patients who are taking benzodiazepans for seizures or drug dependency, seizures may recur if flumazenil is given. The recommended dose of flumazenil is 10 μg/kg up to 1 mg intravenously. Antagonism begins within 1–2 minutes and lasts approximately 1 hour. Since resedation after 1 hour may occur, the patient must be carefully monitored for at least 2 hours. Repeat flumazenil may be necessary. It should be observed that flumazenil will not antagonize the respiratory depression secondary to opiodes. In that situation the opiate antagonist is also required. Flumazenil should not be administered for the routine reversal of the sedative effects of benzodiazepan, but reserved for reversal of respiratory depression.

Until relatively recently, meperidine (Demerol) was a useful agent in longer procedures since its clinical duration of action is 2–4 hours. However, meperidine was never recommended in neonates because its elimination half-life is 3–59 hours. It may be given intravenously in dosage of 0.5–1.0 mg/kg, a maximum being 4 mg/kg. The rectal route is not recommended for endoscopic procedures, nor is the intramuscular one. The time of peak effect for meperidine is 30–90 minutes for oral and intramuscular administration and 1–3 minutes for intravenous administration. In addition to respiratory depression, the active metabolite meperidine (normeperidine) may cause seizures. Meperidine should not be used long-term or in patients with poor renal clearance. The other adverse reactions against meperidine include delirium, nausea, vomiting, urinary retention, pruritis, smooth muscle spasm, and hypotension. Special consideration includes avoidance in patients taking monoamine oxidase inhibitors and in patients with cardiovascular instability. Central nervous system toxicity may occur in patients taking tricyclic

antidepressants and phenothiazines. Patients taking phenytoin or dilantin may have a lesser analgesic effect.

Naloxone reversal of meperidine due to respiratory depression may precipitate seizures caused by normeperidine.

Meperidine in the past was commonly used mixed with promethazine and chlorpromazine as a so-called lytic cocktail. The mixture DPT (Demerol, Phenergan, and Thorazine) is still, on occasion, used by some but it has very long sedation duration, anywhere from 7 to 19 hours. It can also be associated with hypotension seizures, extra pyramidal reactions, and severe prolonged life-threatening respiratory depression. We have not used DPT in more than two decades and no longer see a reason for using it.

Fentanyl is the narcotic that should replace morphine and meperidine as one of the choice for analgesia and sedation for endoscopic procedures in children. Fentanyl is available in a parenteral form or an oral transmucosal delivery form and a transdermal patch delivery form (Duragesic). Duragesic is never to be used for sedation analgesia during procedures in children. Fentanyl is the only narcotic currently approved by the Food and Drug Administration of the United States for sedation analgesia during procedures in children. Approximately 30% of the Fentanyl dose is absorbed via the oral mucosa as the child sucks on a lozenge. The swallowed part of the lozenge is poorly absorbed in the stomach and intestine. Administration usually takes 10–15 minutes. Fentanyl has been used for mildly painful and anxiety-producing situations such as burn dressing changes and skin laceration repair. The 2–3-hour duration of analgesia with Fentanyl also helps with postprocedure pain relief. The incidence of nausea and vomiting is similar to that for other opiate antagonists.

Intravenous Fentanyl in doses of 0.25–0.50 μg/kg has near immediate onset. Doses may be given in small aliquots and carefully titrated to avoid chest wall and glottic rigidity. The duration of action is 30–45 minutes. Close postprocedure observation is required since respiratory depression can outlast analgesia. Adverse effects of both oral and intravenous forms are similar.

Opiod antagonists specifically reverse the respiratory and analgesic effects of narcotics and should be readily available when narcotics are used. Naloxone (Narcan) is the most commonly used antagonist. Opiod antagonist should not be used for routine reversal of sedative effects of narcotics, but reserved for reversal of respiratory depression or respiratory arrest. Naloxone may be given intravenously, intramuscularly, or subcutaneously. The initial dose for respiratory depression is 1–2 μg/kg titrated to effect every 2–3 minutes. A dose of 10–100 μg/kg up to 2 mg may be required for respiratory arrest. Adverse reactions from reverse of analgesia include nausea,

vomiting, tachycardia, hypertension, delirium, and pulmonary edema.

Patients on long-term narcotics should be given narcotic reversal agents in low doses and with extreme caution, since withdrawal seizures and delirium may occur. Patients given naloxone may narcotize after 1 hour. If naloxone is used, the patient should be observed for a minimum of 2 hours.

Systemic anesthetics, ketamine and propofol, have been traditionally used in the operating room by anesthesiologists to produce a state of deep sedation. With appropriate monitoring and personnel, these agents can be safely used outside of the operating room for diagnostic and therapeutic procedures. These drugs are extremely difficult to titrate in children, and so only a state of "conscious sedation" is produced. The child may quickly become deeply sedated and develop airway compromise. These drugs should only be used by anesthesiologists or other practitioners who have specific training in the use of these drugs and have advanced airway management skills, since airway obstruction, apnea, and cardiovascular instability may quickly and unpredictably occur.

Ketamine in low doses can cause intense analgesia with minimal respiratory and cardiovascular depression. Typical doses are 1–2 mg/kg intramuscular or 0.25–0.50 mg/kg intravenous. The intramuscular onset is 2–5 minutes, with a peak of 20 minutes. Duration can be 30–120 minutes. The intravenous onset occurs in less than 1 minute, with a peak effect in several minutes and duration of action in approximately 15 minutes. Higher doses or supplementation with other sedatives or narcotics may produce deep sedation or general anesthesia. Ketamine should always be administered with an antisialagogue (0.02 mg/kg) or glycopyrrolate (0.01 mg/kg) since copious secretions from ketamine alone may induce laryngospasm.

Although it was initially thought that use of ketamine would allow for maintaining airway reflexes, this is not the case. Ketamine will not protect against aspiration. Cardiovascular stability and blood pressure are usually maintained. Typically, ketamine has been associated with dysphoric reactions and hallucinations during emergence up to 12%. It may be reduced by administration of benzodiazepan. Ketamine is also associated with nonpurposeful motion, which limits its usefulness when mobility is necessary. It is contraindicated to use it in patients with head injury, open globe injury, hypertension, and psychosis. It is recognized that ketamine can induce apnea in neonates as well as a decrease response to hypocarbia, laryngospasm, and coughing. There is no antagonist available.

Propofol is a short-acting sedative hypnotic in an Intralipid formulation. It has no analgesic properties, but it does have antiemetic and antipruritic properties. Although small doses of

propofol (25–50 μg/(kg min) can provide "conscious sedation" in adults, deep sedation airway obstruction quickly occurs in pediatric patients. It is generally best administered by titration with an infusion pump by individuals with advanced airway skills. There has been much interest in using this agent outside of the operating room, especially in pediatric intensive care units and in endoscopy. However, cases of fatal metabolic acidosis, mild cardiac failure, and lipemic serum have been reported in children who received this for prolonged periods of time. Short-term sedation with propofol has not been associated with such problems. Propofol may cause pain on injection. This may be circumvented by using large veins or by common administration of an opiod.

Respiratory depression and apnea are very much related to the dose and rate in which propofol is administered. These occur when other central nervous system depressants are used. Hypotension may occur from using the medication, especially when it is given rapidly. Anaphylactic reactions and bacterial contaminations have been described and have been attributed to the lipid emulsion in which it comes. It has also been associated with metabolic acidosis and mild chronic movements.

As indicated, it can cause a concomitant depression if used with other respiratory depressants.

The drug should be decreased in dosage when used in high-risk or debilitated patients. The dosage of this drug should also be lowered if the patients are hemodynamically unstable. Strict aseptic technique must be used when one uses propofol because it may support the growth of microorganisms.

There is no antagonist available for this agent.

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Practical Pediatric Gastrointestinal Endoscopy
George Gershman, Marvin Ament

5 Diagnostic Upper Endoscopy Technique

PREPARATION FOR ESOPHAGEAL INTUBATION

Once sedated, the patient is placed in the left lateral decubitus position with his or her head resting on a small pillow in a neutral position, with the back supported by a folded pillow inserted between the patient and the sidebars of the gurney.

The height of the gurney is adjusted to a level comfortable for the endoscopist and assisting nurse (optimal height corresponds to the endoscopist's elbows). At the beginning of the procedure, the nurse should be standing behind the patient, with her left arm supporting the patient's head in the occipital area and her right palm beneath the chin. This technique will help ensure the constant position of the patient's head during insertion of the endoscope.

The endoscopist should stand approximately 1 ft away from the gurney. This should correspond to the distance of the endoscopist's slightly flexed left arm from the patient's mouth. The position is optimal for aligning the endoscope with the pharyngeal and esophageal axis and for providing good visualization of the tongue. Placement of a bite-guard is mandatory for all children before the procedure, except infants without teeth.

The bite-guard serves three important functions:

1 Protection of the endsocope
2 Facilitation of proper positioning of the endoscope between the palate and the tongue
3 Anchoring of the suction catheter

A modern bite-guard consists of a plastic cylinder with a front hollow bumper and side clips with an attached strip of ribbon, which helps to keep it centrally located between teeth during the procedure.

Despite clever design, close attention should be paid to the position of the bite-guard to avoid mechanical damage to the endoscope when the child becomes more awake or agitated.

In younger children, insertion of a bite-guard is simplified by adequate sedation. Appropriate position of the bite-guard should be verified by pulling the lips gently along the outside bumper to protect them from accidental entrapment between the teeth and the bite-guard.

ASSEMBLING THE EQUIPMENT AND PREPROCEDURE CHECKUP

1 Insert the connection plug into a light source tightly. A faulty connection may result in a disrupted or absent image on the monitor and malfunction of the air/water delivery system.
2 If using a videoendoscope, connect the endoscope and videoprocessor with the special cable.
3 A fiberscope can be connected to the videoprocessor with a special adapter to transmit an endoscopic picture to the monitor.
4 Some of the older "Olympus Co" light sources require an additional connection through a small cable (part of the scope to videoprocessor connector) for selection of OES (Olympus endoscopy system) mode for fiberscopes and 100–200 mode for videoendoscopes.

False connection or wrong mode selection will result in improper white balance, excessive brightness, or a "whiteout" screen, which results in loss of the endoscopic image.
5 Push the ignition button to activate the light source.
6 Check the white balance.
7 Fill the water container up to three-fourths of its capacity with sterile water.
8 Fill the water channel by pressing and holding down the air/water valve and confirming vigorous water spurting from the nostril. If water is not running out at a decent pressure or is just barely dripping out, check the status of the air pump, connection of the light source and the water container to the endoscope, and integrity of the "O" ring. If the problem persists, tighten the cap of the water container and determine if the air/water valve is properly mounted. Consider sequential replacement of an air/water valve, water container, and the endoscope if all other options have been exhausted.
9 Adjust the air pump to medium intensity to prevent excessive insufflation of the stomach, which provokes patient irritability and retching secondary to increased intra-abdominal pressure, elevation of the diaphragm, and decreased tidal volume especially in infants and toddlers. Excessive use of air increases the risk of vomiting and aspiration. In our opinion, the use of the high air pressure setting is limited to percutaneous endoscopic placement of gastrostomy tubes.
10 Check and adjust suction intensity. If it is inadequate, check the suction system in a stepwise plan. First, make sure that the suction switch is in "On" position; the suction cable is tightly connected to the endoscope and the suction canister. If suction is still inadequate, reassemble the suction canister properly. Then, concentrate on the suction valve: pull it out for visual inspection, dip it in water, and reinsert it back by pressing down into

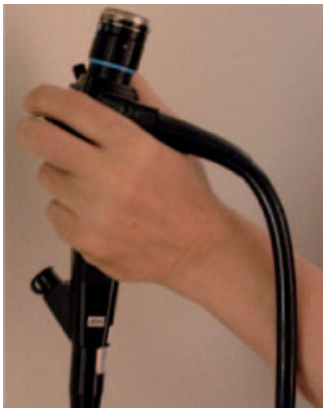

Fig. 5.1 Control panel handling. The control panel is in the left palm between the fourth and fifth fingers. Slight extension of the arm and the connecting tube hanging behind the thumb balances the weight of the control panel and further secures the correct grip.

the suction nostril of the control panel until a soft click occurs. Replace the endoscope if all previous steps have failed.

11 Wipe the lens of the endoscope with alcohol swab if the image is blurred.

ENDOSCOPE HANDLING

The endoscopist holds the control panel of the endoscope in the left, slightly extended palm using the fourth and fifth fingers, with the connecting tube hanging behind the thumb (Fig. 5.1). The index and the middle fingers are positioned comfortably above the suction and air/water valves, respectively (Fig. 5.2). This allows the endoscopist to use the thumb for rotation of the large up/down (U/D) knob in a clockwise or counterclockwise direction (Fig. 5.3). The middle finger can assist with extensive rotation, by locking the knob from above and leaving the thumb free for continuous movement from below (think about ratchet-wheel) (Fig. 5.4).

An experienced endoscopist can also use the thumb for simultaneous adjustment of the small right/left (R/L) knob. Lateral deflection of the bending portion of the endoscope can be produced by twisting the left hand and/or forearm in clockwise or counterclockwise direction. Generated force is transmitted from the control panel to the shaft of the endoscope.

The effectiveness of torque technique is directly related to the degree of straightening of the working part of the endoscope between the control panel and the bite-guard. Moving the right shoulder forward for counterclockwise rotation and the left shoulder for clockwise rotation reinforces it. Thus, appropriate manipulation with the U/D knob and positioning of the endoscope and the left arm are sufficient for precise orientation without frequent movement of the R/L knob.

Fig. 5.2 Approach to the air/water and suction buttons. The index and the ring fingers are free to work with the air/water and suction buttons.

Fig. 5.3 Manipulations with the R/L and U/D knobs. The thumb is the main tool for rotation of the U/D and R/L knobs.

Fig. 5.4 Technique of the extensive rotation of the control knobs. The middle finger can serve the function of the locker during extensive rotation of the knobs: ratchet-wheel technique.

The R/L knob is useful for targeting the biopsy, U-turn maneuver, and intubation of the second portion of the duodenum.

The index and the middle fingers of the left hand operate the suction and air/water valves, respectively. The endoscopist uses the right hand to advance, withdraw, and rotate the shaft of the endoscope. In addition, the right hand is used for handling biopsy forceps or other accessories.

TECHNIQUE OF ESOPHAGEAL INTUBATION

There are three types of esophageal intubations: direct observation, blind, and finger assisted. Direct observation technique is the best and safest for pediatric upper gastrointestinal (GI) endoscopy with the forward view endoscopes. After all preparations have been made and the endoscope has been found to be properly functioning, it is lubricated to the 15-cm mark and held by the endoscopist as described above. The endoscopist holds the control panel in the left hand and the shaft in the right hand between the thumb, index and middle finger at the 20-cm mark. The bending portion of the endoscope should be straightened to achieve vertical movement when the U/D knob is used. Just before the insertion of the scope into the mouth, the tip of the endoscope should be bent downward (in general, the smaller the child, the smaller the radius of bending). It will mark the plane of the endoscope, which should be aligned with the longitudinal axis of the pharynx by clockwise or counterclockwise rotation.

At the beginning, full attention should be paid to the proper placement of the endoscope into the mouth (Fig. 5.5). It is especially important in infants and toddlers due to the relatively small space to work with and easy displacement of the tongue posteriorly and superiorly by the bite-guard.

The rule of thumb is to concentrate on the child (not on the screen) until the endoscope is placed properly along the midline

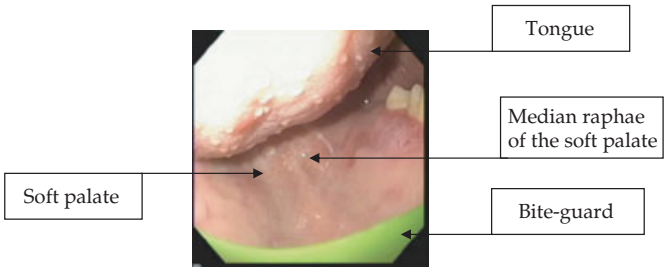

Fig. 5.5 The initial phase of the esophageal intubation. The endoscopist should concentrate of the proper positioning of the scope in the oral cavity: the view of the tongue and the soft palate through the bite-guard.

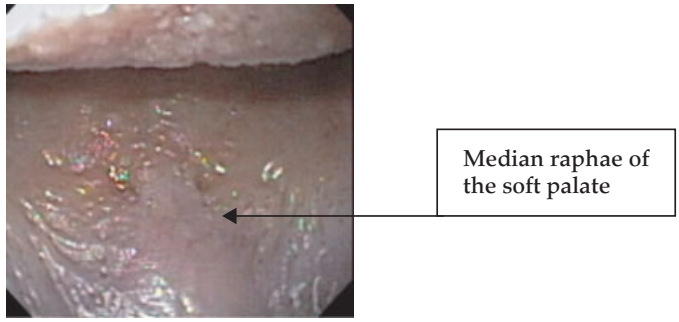

Fig. 5.6 The correct approach of the pharynx. The midline of the tongue and the palate shows the correct direction of the insertion.

of the tongue and the tip of the scope is no longer visible (Fig. 5.6). If the tongue is flipped up or sticking out, attempts to insert the endoscope lead to further displacement of the tongue posteriorly, increasing the risk of apnea and accidental trauma of the buckle or pharyngeal mucosa due to lateral displacement of the instrument. In this specific instance, it is useful to remove the bite-guard, fit it over the shaft, slide it back, and transfer the endoscope to the assistant, who has to keep it parallel to the longitudinal pharyngeal axis.

Meanwhile, the endoscopist inserts the left index finger into the child's mouth and using it as a tongue blade pushes the tongue inferiorly and anteriorly, while placing the endoscope over the tongue with the right hand. Then, the bite-guard is fitted back into the mouth. Finally, the endoscopist takes over the control panel and adjusts the position of the endoscope as described above. At this point, all further manipulations with the scope should be carried on under direct observation of the picture on the monitor. Remember that the endoscopic image is reversed due to bending of the instrument. In other words, relatively pale tongue with its rough texture occupies the upper part of the screen, while the bright-pink and smooth palate appears at the bottom of the monitor (Fig. 5.7). Move the endoscope slowly forward along the midline and gently angle it down by rotating the U/D knob counterclockwise. It will facilitate sliding into the pharynx over the root of the tongue, which may be seen transiently as a papilla structure (Fig. 5.8).

The lumen of the oropharynx could be lost momentarily just before the pharynx is revealed. If adequately angled, the endoscope is slowly inserted forward. In some instances the posterior wall of the pharynx will be viewed, but oftentimes the first structure to emerge will be the epiglottis. It will occupy the upper part of the screen as a crescent-shaped object in a horizontal direction (Fig. 5.9). Failure to find the epiglottis indicates that the endoscope was advanced too far anteriorly (above the epiglottis) or

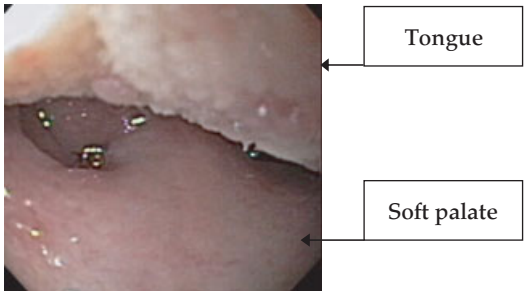

Fig. 5.7 The reverse image of the tongue and the palate. The tongue is in the upper part of the screen while the soft palate occupies the lower part of the monitor. The beginners should use to the reversed images created by the endoscopes.

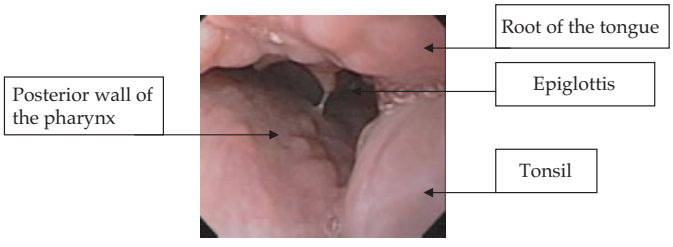

Fig. 5.8 The root of the tongue. The root of the tongue appears as the rough texture, papilla structure. It may be seen briefly or not at all during routine procedure. However, careful examination of this area and tonsils should be attempted in children with suspected posttransplantation lymphoproliferative disorder.

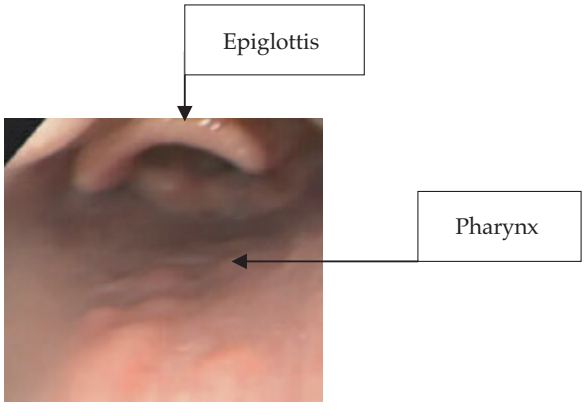

Fig. 5.9 The initial view of the epiglottis. The epiglottis should be found and seen clearly before esophageal intubation is attempted.

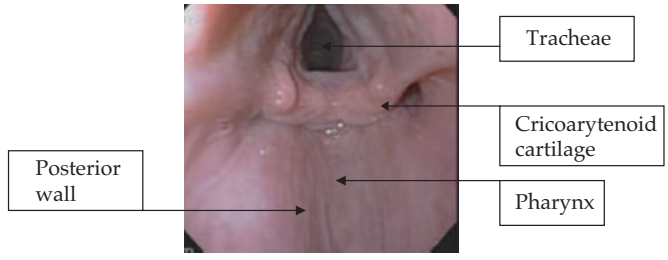

Fig. 5.10 The endoscopic anatomy of the larynx: the panoramic view.

too close to the cricoarytenoid cartilages, or was angled laterally. In any circumstances when the orientation is lost, follow the rule of thumb: pull the endoscope back until the orientation is fully restored. In this particular case, pull the endoscope back to the first recognizable structure, for example, the uvula pointed up from the low portion of the screen, laterally located tonsils, or "median raphae" of the tongue from above. Reposition the shaft of the endoscope along the midline, push it forward slowly, and rotate the U/D knob counterclockwise simultaneously. Stay on the same track until the larynx is clearly viewed. Stop advancing if resistance is felt or if the picture becomes diffusely pink and blurry.

The larynx has a triangular shape, with the epiglottis above, two small spherical structures (i.e., the arytenoid cartilages at the bottom) and an aryepiglottic fold on a side (Fig. 5.10). True vocal cords can be occasionally seen as a white/silver upside down letter "V" (Fig. 5.11). Close view of the vocal cords is a warning sign of excessive deviation of the endoscope anteriorly. Remember that the esophageal orifice is hiding behind the cricoarytenoid cartilages (i.e., at the very bottom of the screen). In order to reach

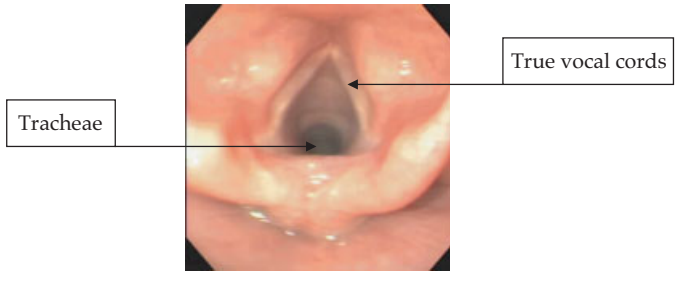

Fig. 5.11 The endoscopic appearance of the vocal cords. A close capture of the vocal cords indicates that the tip of the scope is advanced too far anteriorly. The shaft must be pulled back a few centimeters immediately and the tip should be deviated down toward the posterior wall.

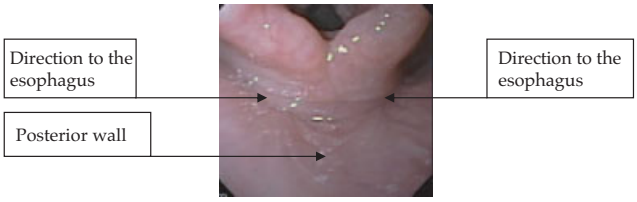

Fig. 5.12 The close-up view of the cricoarytenoid cartilages. The esophageal orifice is hiding behind/posteriorly to this structure: below the cliff of the cartilage.

this point, the tip of the endoscope should be angled downward toward the posterior wall of the pharynx by rotation of the U/D knob in clockwise direction. The opened cricopharyngeal portion of the esophagus can be seen briefly during swallowing as a dark ring slightly lateral from the larynx.

Direct midline intubation of the esophagus is practically impossible due to significant pressure generated by the larynx toward the posterior pharyngeal wall. This resistance will push the endoscope either to the right or to the left of the larynx (Fig. 5.12). In the first case, rotate the shaft clockwise to about one-fourth turn. In the second case, adjust the shaft to the same degree counterclockwise (Fig. 5.13). In either case, advance it forward slightly until you see the mucosal fold crossing the upper part of the screen in a diagonal fashion (Fig. 5.14). If the direction of insertion is unchanged at this point, the endoscope will enter the "periform recess." Rotate the shaft in the opposite direction and angle the tip of the endoscope up, by rotating the U/D knob counterclockwise (Fig. 5.15). If the resistance is diminishing, keep advancing the endoscope along the sliding-by mucosa. Spontaneous opening of the esophagus helps to adjust the position of the endoscope and simplifies the intubation process. In case of persistent resistance or loss of orientation, pull the endoscope back to the level of the arytenoids cartilage and repeat the intubation from the opposite side of the larynx.

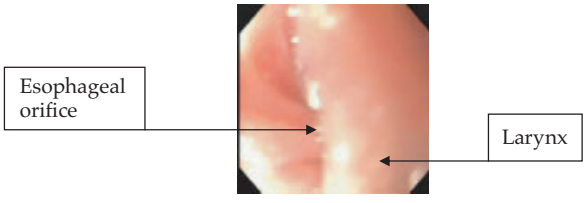

Fig. 5.13 Side-view of the groove between the lateral wall of the larynx and pharynx. The shaft was rotated counterclockwise to approach the esophageal orifice. Direct intubation of the esophagus along the midline is impossible due to extensive pressure between the posterior wall of the larynx and anterior wall of the pharynx.

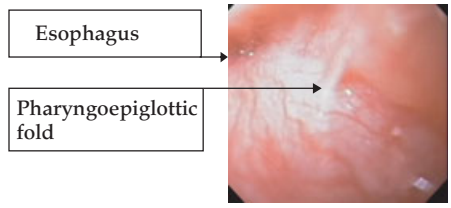

Fig. 5.14 The pharyngoepiglottic fold. It signals to switch rotation and deviate the tip of the scope upward.

In neonates and small infants, additional rotation of the endoscope once it has been already inserted into the cervical esophagus is necessary to overcome the resistance and reduce the force pushing the endoscope forward into the esophagus.

During swallow, the larynx moves superiorly to protect the airway. It is useful to pull the endoscope back with the swallow and advance it quickly forward through the briefly opened pharyngeal portion of the esophagus. When the tip of the endoscope is submerged between the cricoid cartilage and posterior wall of the pharynx longer than 10–15 seconds, it may induce irritability and agitation even in well-sedated patients. Apnea and/or bradycardia, especially in infants and toddlers, may also occur due to constant pressure on the larynx and irritation of the nearby superior laryngeal nerve. If intubation of the esophagus lasts more than 20 seconds, it is wise to pull the endoscope out until the child regains normal breathing.

In addition, resistance to passage of the endoscope, the presence of light in the lateral neck, or loss of clear picture warrants the withdrawal of the endoscope.

To facilitate subsequent esophageal intubations, an endoscopist should wait for spontaneous opening of the esophageal orifice or use air insufflations and/or brief (1 or 2 s) water irrigation. To avoid aspiration, this technique should be used only when the tip of the endoscope has been inserted behind the larynx and deviated from the midline.

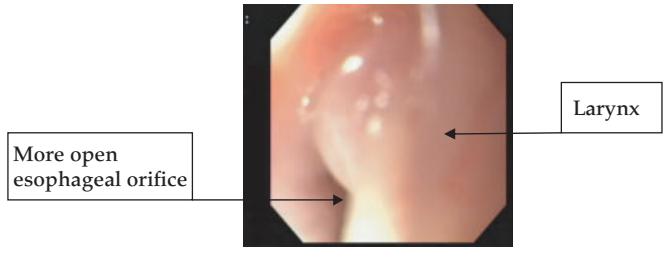

Fig. 5.15 Close-up view of the esophageal orifice. Rotation in the opposite direction allows positioning the tip of the scope toward the esophagus and away from the "periform recess".

After successful intubation of the upper esophageal sphincter, the endoscope should be advanced strictly along the lumen. The cervical esophagus is closed by tonic contractions of the cricopharyngeal muscle. It is only partially seen during antegrade insertion of the endoscope. Therefore, air insufflation is necessary to keep the tip of the endoscope on a safe distance from the esophageal wall. More detailed examination of the cervical esophagus is feasible with muscle relaxants, e.g., during foreign body removal. Advancement of the endoscope toward the thoracic inlet is facilitated by light clockwise rotation.

The thoracic portion of the esophagus is constantly opened except during brief peristaltic closures. It makes detailed examination of the entire tubular esophagus quite easy without air insufflation. The distention of the esophagus with air is needed only in few occasions such as extraluminal compression, foreign bodies, esophageal varices, and severe esophagitis. Intermittent clockwise or counterclockwise rotations of the endoscope are necessary to keep the instrument in the middle of the esophageal lumen. This position of the endoscope is optimal for a panoramic view of the esophagus.

The lumen of the thoracic esophagus is narrowed down at the area of the so-called second physiological narrowing created by the left main bronchus. It is always unilateral (Fig. 5.16). Bilateral narrowing of the thoracic esophagus is pathological, and further workup should be considered to rule out double aortic arch or aberrant subclavian artery.

The useful landmark of the distal esophagus is a pulsation of the left atrium. Near the level of the diaphragm the distal esophagus is tapering down in a funnel shape (Fig. 5.17). It deviates to the left, passing through the diaphragmatic notch. The border between the relatively pale esophageal and brighter gastric mucosa, the so-called Z-line, is slightly irregular (Fig. 5.18). The location of the Z-line in relation to the hiatal notch has normal variations. In general, elevation of the Z-line by 2 cm or more

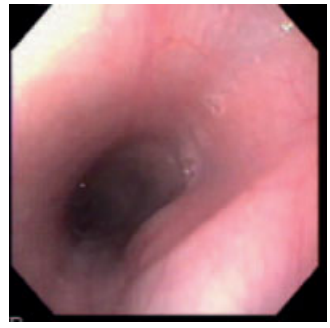

Fig. 5.16 The second physiological narrowing of the esophagus. It does not have sharp borders and is always unilateral.

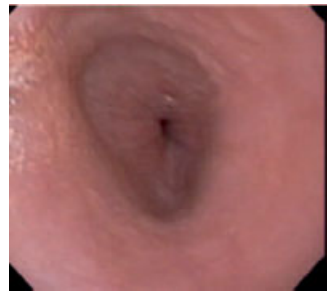

Fig. 5.17 The distal esophagus. It tapers down toward the hiatal notch.

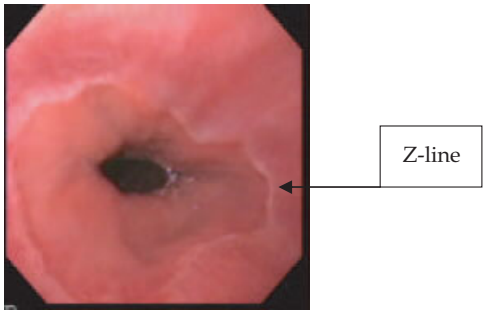

Fig. 5.18 Z-line. The junction between the pale esophageal and richer colored gastric mucosa is slightly irregular. It is located at the level or within 2 cm above the hiatal notch.

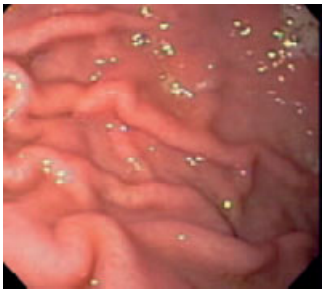

Fig. 5.19 Prominent fold of the greater curvature of the stomach. Appearance of these folds is the sign of a successful intubation of the stomach.

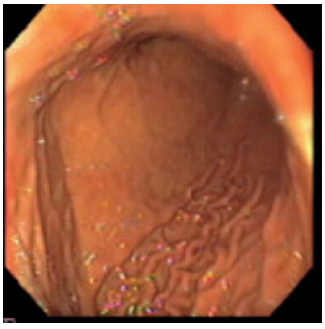

Fig. 5.20 Panoramic view of the gastric body. It can be achieved by clockwise rotation of the shaft and by elevation of the tip of the scope.

above the diaphragm is abnormal. For correct estimation of the location of the diaphragmatic hiatus, the endoscopist should find the area where esophageal lumen closes during inspiration and opens with expiration. This is not always easy to do during antegrade endoscopy in a deeply sedated child with shallow breathing. The location of the diaphragm in relation to the Z-line becomes more obvious with retrograde observation. To follow the natural course of the abdominal portion of the esophagus, the endoscope has to be slowly advanced and rotated counterclockwise with simultaneous elevation of the tip of the instrument. Straightforward approach to enter the stomach will result in loss of orientation due to close proximity of the posterior wall of the cardia or upper body. The stomach is recognized by the folds of the greater curvature between 5 and 7 o'clock directions as well as by a pool of mucus (Fig. 5.19). At this point, the endoscope should be rotated clockwise and bent downward until appearance of a panoramic view of the gastric body is achieved (Fig. 5.20). Four slightly outlined folds between 1 and 3 o'clock directions highlight the lesser curvature. These folds disappear quickly during insufflation.

To assure good patient tolerance of the procedure, it is important to minimize the amount of air pumped into the stomach. It is especially important in neonates and infants, who are quite sensitive to gastric distention and may become irritable, retch, and develop respiratory distress or bradycardia.

Further rotation and bowing of the tip of the endoscope upward will facilitate the advancement of the instrument toward the gastric angularis. The junction of the gastric body and antrum is marked by a prominent gastric angle from above and loss of folds of the greater curvature from below (Fig. 5.21). At this point it is useful to elevate the tip and advance the endoscope further toward the antrum.

Resistance or loss of orientation warrants pulling back. In cases of a so-called cascade stomach, it is difficult to reach pylorus just by pushing the endoscope forward. Instead, move the tip of the endoscope upward, advance it forward, rotate the shaft clockwise, and pull it back. Repeat this maneuver and push the endoscope slightly deeper each time until the pylorus appears on the screen.

A normal pylorus looks like a spiral ring, which disappears during peristalsis. The length of the normal pylorus channel during relaxation is approximately 3–5 mm.

For successful intubation of the pylorus, the endoscope should be advanced along the prepyloric folds. The tip has to be bent slightly downward to avoid flipping into a retroflexed position (Fig. 5.22).

If the pylorus is lost during peristalsis, it is useful either to wait until it opens up spontaneously or to pull the endoscope 3–4 cm backward to regain a panoramic view of the prepyloric antrum.

Gentle advancement is enough to pass the endoscope through the pylorus. In rare cases, attempts to bypass the pylorus will move the endoscope away from the target.

In such instances it is useful to pull the endoscope back into the gastric body, decompress the stomach, and approach the pylorus as close as possible.

Keep pressure on the pylorus and turn the side knob to angle the endoscope toward the visible portion of the pylorus until the endoscope begins moving toward the center of the pyloric ring. Sometimes it is useful to pull the endoscope back slightly when it is almost embraced by the pylorus.

Passage of the pylorus is manifest by disappearance of resistance. The endoscopist must be careful to avoid blind trauma of the duodenal bulb due to rapid advancement of the endoscope.

The duodenal bulb should be examined carefully before exploration of the second portion of the duodenum. The endoscope has to be pulled back toward pylorus slowly and deviated to the right to achieve a panoramic view of the duodenal bulb (Fig. 5.23).

There is a "blind" zone in the proximal part of the duodenal bulb between the 3 and 6 o'clock position. Rotating the patient into the prone position facilitates exploration of this area.

The walls of the duodenal bulb are labeled traditionally as anterior, posterior, lesser, and greater curvatures (Fig. 5.24).

Certain corrections in the orientation inside the duodenal bulb should be made with respect to the stage of the upper endoscopy: advancement of the endoscope toward the duodenum is associated with varied degree of loop formation. Alternatively, the endoscope is more or less straightened on the way back to the stomach (Fig. 5.25).

An accurate location of lesions in the duodenal bulb is important for patients with bleeding duodenal ulcer. Bleeding ulcers on the posterior wall of the distal portion of the duodenal bulb or the superior duodenal angle are associated with a high risk

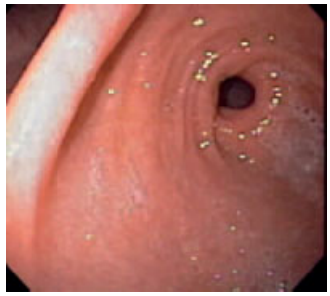

Fig. 5.21 Gastric angularis. The detail image of the angularis can be easily obtained during withdrawal phase of the procedure: (i) position the tip of the scope at the level of the distal body and (ii) rotate the scope counterclockwise and advance forward.

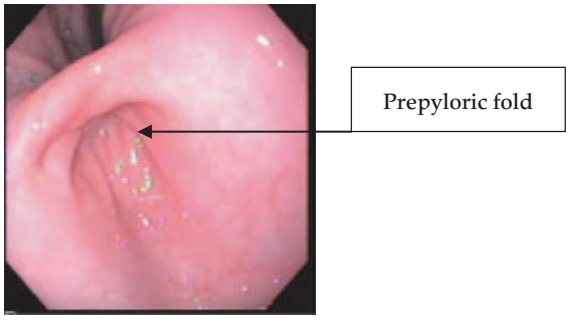

Fig. 5.22 Panoramic view of the antrum. At this stage of the procedure the tip of the scope should be deviated down to prevent flipping of the shaft into U-turn position. The prepyloric folds are pointed toward the pylorus.

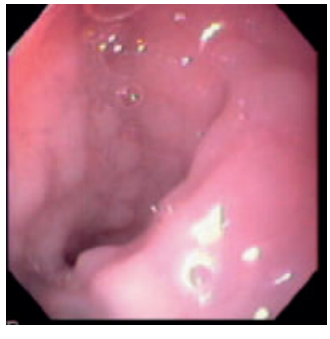

Fig. 5.23 Panoramic view of the duodenal bulb. It is useful for correct engagement of the endoscope beyond the superior duodenal angle.

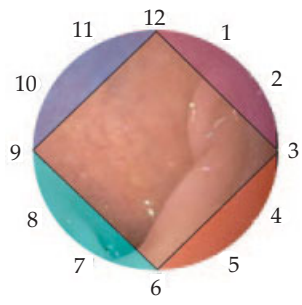

Fig. 5.24 Endoscopic mapping of the duodenal bulb during insertion phase of the procedure: anterior wall is located between 6 and 9 o'clock; posterior wall is located between 12 and 3 o'clock; lesser curvature or medial wall is located between 9 and 12 o'clock; greater curvature or lateral wall is located between 3 and 6 o'clock.

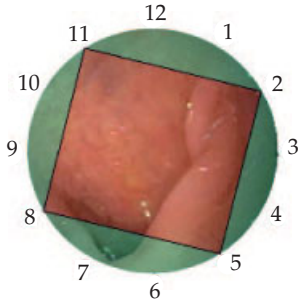

Fig. 5.25 Mapping of the walls of the duodenal bulb after reduction of the gastric loop: anterior wall is now located between 5 and 8 o'clock; posterior wall is now located between 2 and 11 o'clock; lesser curvature or medial wall is now located between 8 and 11 o'clock; greater curvature or lateral wall is now located between 2 and 5 o'clock.

of recurrence due to intense blood supply to the area and close proximity of the pancreas.

"Pull-and-twist" technique

Intubation of the second portion of the duodenum requires
- straightening of the endoscope and
- clockwise rotation.

The goal of the first maneuver is restoration of the normal anatomy of the stomach, which is always inadvertently disturbed by the endoscope pushed forward and looped on its way to the duodenum. The second element of the technique is clockwise rotation of the shaft. This is necessary to achieve an axial alignment between the stomach and the duodenum and to "open up" the twisted superior duodenal angle.

Upon entering the duodenal bulb, a lumen of the transitional zone between the distal duodenal bulb and the superior duodenal angle appears as a slot, which lies quite often in a plane of "AC" line (Fig. 5.26).

In this scenario, exploration of the second portion of the duodenum begins with the advancement of the endoscope forward and positioning of the endoscope just below the AC line. The next step involves bending the tip of the endoscope up and to the right in the 5 o'clock direction. This will anchor the endoscope to the superior duodenal angle. Finally, rotate the shaft roughly 90° clockwise and pull it back simultaneously until the duodenal lumen is clearly visible.

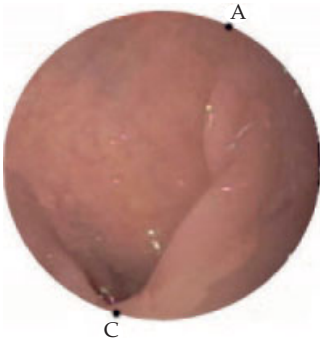

Fig. 5.26 Appearance of the transitional zone between the duodenal bulb and the superior duodenal angle. AC line reflects the usual configuration of this transitional zone.

If duodenal folds are sharply demarcated but the duodenal lumen is still obscure, rotate the endoscope counterclockwise about a quarter turn and orient the tip in the 10–11 o'clock directions.

Intubation of the second portion of the duodenum can be challenging if the transitional zone between the distal duodenal bulb and superior duodenal angle is almost horizontal (Fig. 5.27). In this case, attempt the standard pull-and-twist technique first. If unsuccessful, pull the endoscope back to the upper portion of the gastric body, decompress the stomach, and repeat duodenal intubation. The keys to success are minimal insufflation and avoidance of pushing the endoscope straightforward against increasing resistance. If the technique is not working, position the tip of the endoscope in the middle of the duodenal bulb and rotate the endoscope counterclockwise. It might straighten the axis of the proximal duodenum and "unlock" the superior duodenal angle. While the duodenal lumen becomes wider, continue counterclockwise rotation and pull the endoscope back simultaneously until the second portion of the duodenum is reached.

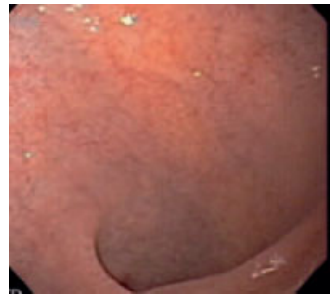

Fig. 5.27 Horizontal configuration of the transitional zone between the duodenal bulb and the superior duodenal angle. Decompression of the stomach and reduction of the gastric loop should precede an exploration of the second portion of the duodenum. Counterclockwise rotation may facilitate intubation of the duodenum beyond the duodenal bulb.

Intubation of the second portion of the duodenum in neonates and infants is quite simple with a thin 5-mm endoscope: it requires only gentle advancement. The 7- and 8-mm pediatric endoscopes are more rigid and difficult to straighten during duodenoscopy in neonates or infants. An attempt to perform the pull-and-twist maneuver in this instance usually results in displacement of the endoscope back into the stomach. Instead, push the endoscope gently toward the superior duodenal angle and move the tip to the right.

If resistance is minimal, continue advancement. As soon as "crescent" of the duodenal lumen appears on the screen, rotate the endoscope counterclockwise slightly (about 15–20°) and adjust the position using the U/D knob to achieve a panoramic view of the second portion of the duodenum. Advance the endoscope forward until the duodenal lumen begins unfolding or moving away due to increased resistance and looping of the endoscope in the stomach.

The hallmark of the second portion of the duodenum is the papilla of Vater (Fig. 5.28). Although its anatomical position is obviously constant in an individual patient, the endoscopic mapping may vary between the intubation, when the duodenum is more stretched and twisted, and the withdrawal phase of the procedure, when it is straighter.

During insertion, the major papilla is usually found between the 9 and 10 o'clock directions on the medial wall of the second portion of the duodenum. During withdrawal of the endoscope from the distal duodenum, the location is shifted toward the 12 o'clock direction.

It is not always easy to find the major papilla or to obtain the detailed images with the forward view endoscopes. This limitation

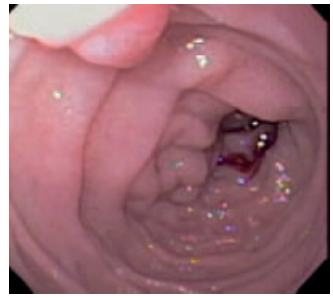

Fig. 5.28 Major duodenal papilla of Vater. It is the hallmark of the second portion of the duodenum. It is seen more clearly during withdrawal phase at 11–12 o'clock location.

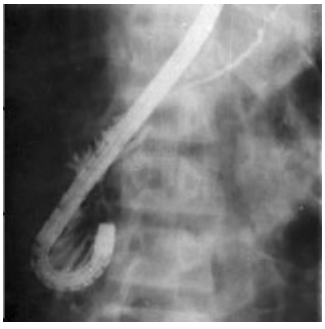

Fig. 5.29 Retroflexion of the scope in the duodenum. This technique allows a detail examination of the major duodenal papilla.

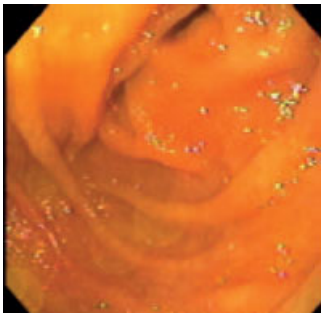

Fig. 5.30 The endoscopic appearance of the duodenum at the level of the ligament of Treitz.

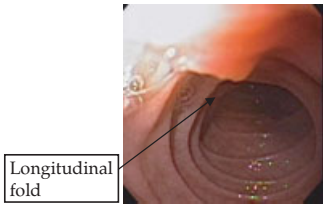

Fig. 5.31 The longitudinal fold. It is the best guide to the major duodenal papilla.

is derived from the technical design of the objective lens of these instruments, which create a tangential and quite narrow view of the convex medial wall of the descending duodenum.

To overcome this limitation, the tip of the endoscope should be placed almost above and perpendicular to the major papilla, i.e., in retroflexion (Fig. 5.29).

It is more practical and easy to perform this maneuver after exploration of the distal duodenum. In many cases, it can be achieved by pulling back the endoscope in order to straighten the shaft in the stomach along the lesser curvature. As a result, this will create force to push the tip of the endoscope forward.

The hallmark of the third portion of the duodenum is the superior mesenteric artery responsible for a prominent pulsation of the right part of the duodenal wall.

The lumen of the fourth portion of the duodenum is narrowed at the level of ligament of Treitz (Fig. 5.30).

Maximal straightening of the endoscope in the stomach limits the depth of the duodenal intubation. In majority of children, the third portion of the duodenum can be reached with the above-described technique.

After examination of the distal duodenum is completed, pull the endoscope back and angle it up slowly in the 12 o'clock direction until the longitudinal fold is revealed (Fig. 5.31). At this point, the major papilla can be reached either by careful withdrawal by an additional 3–4 cm and slight rotation in the counterclockwise direction, or by gently pushing the endoscope forward with upward and right side deflection, using the both control knobs with simultaneous counterclockwise twisting.

More detailed images of the papilla of Vater can be obtained with a side view duodenoscope (Fig. 5.32).

The small duodenal papilla is located 3–4 cm proximal to the major one. It can be found in the right upper corner of the lumen between the 1 and 2 o'clock position. It is a smooth, 4–5-mm structure, which resembles a sessile polyp.

Withdrawal phase of upper GI endoscopy is the best for detailed observation of the entire duodenum, stomach, and the esophagus.

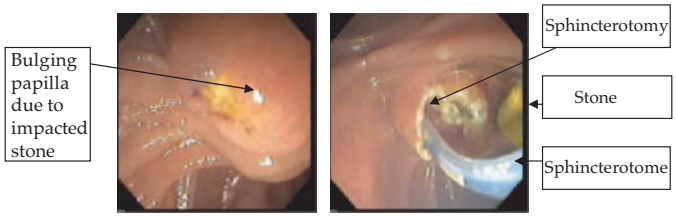

Fig. 5.32 The major duodenal papilla. The side-view duodenoscope allows obtaining the detail image of the major duodenal papilla and performing endoscopic retrograde cholangiopan-creatography (ERCP) and sphincterotomy.

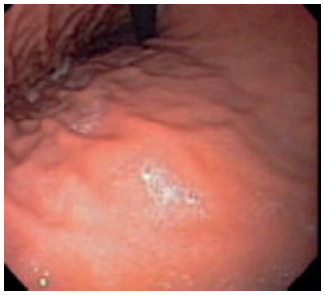

Fig. 5.33 The view of the gastric body during initial phase of the retroflexion maneuver.

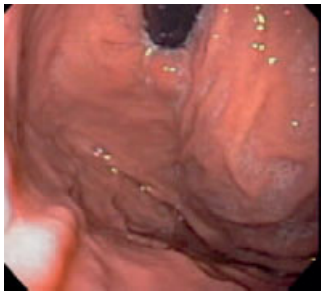

Fig. 5.34 Appearance of the cardia after partial withdrawal of the shaft during retroflexion maneuver.

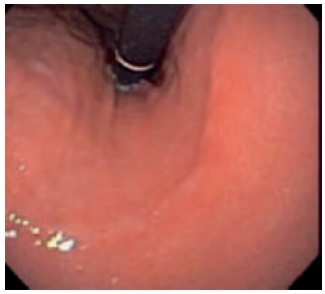

Fig. 5.35 More detail view of the cardia with additional withdrawal of the scope.

Retroflexion in the stomach or the so-called J-maneuver is the best technique for careful exploration of the gastric cardia and fundus. It is reasonable to perform retroflexion after examination of the duodenum to avoid overinflation of the stomach. In patients with acute GI bleeding the stomach may contain a large amount of blood and clots. In this circumstance, it is more practical to attempt retroflexion in the beginning of the procedure, while the stomach is not filled with extra fluid added during irrigation and for cleaning away the blood from the lenses.

The retroflexion technique consists of a few steps:

First, the tip of the endoscope should be positioned in the middle of the gastric body and oriented toward the anterior wall in a 10 o'clock direction. Next, bend the tip of the endoscope further up and advance the shaft forward until the angularis emerges diagonally, separating the gastric body on the left from the antrum on the right part of the screen (Fig. 5.33).

Pull the endoscope back and rotate it clockwise to achieve a close-up view of the fundus (Figs. 5.34 and 5.35).

For detailed image of the cardia, target biopsy, or hemostasis of the region, find the grooves between the shallow folds of the lesser curvature during counterclockwise rotation and pull the endoscope back slowly. Recognition of Z-line indicates the end of withdrawal (Fig. 5.36). This part of retroflexion maneuver should be performed with caution to avoid an accidental impaction of the sharply bended tip of the endoscope in the distal esophagus.

To get away from the cardia, safely push the endoscope forward, rotate it clockwise, and return the control knobs in neutral position. Check and unlock the control knobs if they lock accidentally, to avoid a blind trauma of the gastric mucosa. Decompress the stomach as much as possible before extubation.

It is very important to straighten the shaft between the control panel and bite-guard to facilitate orientation and transmission of the rotating force to the tip of the instrument. Careful

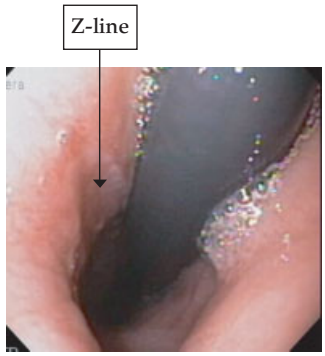

Fig. 5.36 Close up-view of the cardia. This helps to examine the area and to delineate the spatial relationship of the Z-line and the hiatal notch.

examination of the esophagus should be carried out until the endoscope is withdrawn completely.

Biopsy technique

Histological verification of many diseases involving the upper GI tract (e.g., esophagitis, gastritis, and celiac disease) is crucial for a definitive diagnosis. In this respect, sufficient tissue samples and proper orientation are key to correct interpretation of the biopsy.

It is always possible to obtain an adequate tissue sample (even with small forceps) if an endoscopist is familiar with the appropriate technique.

There are three universal rules:

1 Endoscopic biopsy is not a blind procedure.

2 The forceps should not be advanced more than 2 cm beyond the tip of the scope.

3 Forceful pushing of the forceps up against a wall is a dangerous and ineffective way to obtain more tissue.

Technically, esophageal biopsy is more difficult than either gastric or duodenal biopsy.

The most common indication for esophageal biopsy in pediatrics is suspected esophagitis. For correct interpretation, each biopsy site should be located using the Z-line as the reference point. To avoid confusing results, at least two biopsies have to be taken from 2 cm above the gastroesophageal junction.

The number and the site of the gastric and duodenal biopsies are determined according to suspected GI pathology. For example, biopsy from four different sites is recommended to confirm *Helicobacter pylori* (HP) infection: two samples have to be taken from the prepyloric antrum including a sample for CLO (*Campylobacter*-like organisms) test, one from the lesser curvature of the antrum, and one from the greater curvature of the distal body.

In case of an ulcers or erosions, biopsies should be taken from their margins. Special attention should be paid to the first biopsy performed. It is important because the lesion may be covered with blood and subsequent target biopsies could be difficult to perform.

The best site for a duodenal biopsy is the edge of the valvulae conniventes. A perpendicular orientation of the forceps to the mucosal folds eliminates excessive pressure on the tissue, prevents mucosal trauma and artifacts of the biopsy, and augments the size of the sample.

Comparison of endoscopic and blind duodenal biopsies showed that the former could substitute for blind capsule biopsy for diagnosis of celiac sprue and other mucosal diseases. If celiac sprue is suspected, at least four samples of tissue

must be obtained from the second or the third portion of the duodenum.

A proper orientation and mounting of GI biopsy specimens are crucial for correct histological diagnosis, especially of celiac sprue, inflammatory bowel disease, and surveillance for dysplasia in patients with long-standing ulcerative colitis, Barrett's esophagus (BE), and polyps. This does not prolong an endoscopic procedure for more than 5–7 minutes. A well-trained endoscopic nurse spends an additional minute per specimen. Although a naked-eye orientation is possible in majority of the specimens obtained by the regular forceps, a simple magnifying glass lamp may be useful. Several steps are involved in proper mounting technique:

- Wearing of tight-fitting gloves free of talcum
- Gentle transferring of a specimen from the open forceps to the index finger with or without the help of dissecting needle
- Uncurling of a specimen with a light touch of the side of the dissecting needle until the cleavage surface is exposed
- Recognition of the surface area: mucosal site of the specimen is more hemorrhagic–appearing and glistening
- Complete uncurling of the specimen facing submucosal site up
- Transferring the specimen from the index finger to the mesh resting on the thumb of the same hand:
  - Touching the supporting mesh with half of the specimen
  - Sweeping the visible part of the specimen to the mesh by placing a side of the dissecting needle between the biopsy specimen and the index finger
  - Moistening of the needle with water
  - Pushing of the remaining part of the specimen away from the index finger by the side of the needle
  - Placing the mesh with mounted specimen upside down into the fixative solution to prevent it from floating off the supporting mesh.

The labeled bottle with fixative solution should contain not more than two to three biopsy specimens from each site of GI tract, e.g., two specimens from the gastric body, antrum, etc.

Plastic mesh is a suitable supporting material for different fixative techniques. The choice of supporting material for formalin fixation is the prerogative of the particular pathology laboratory.

INDICATIONS FOR UPPER ENDOSCOPY

There are three general categories of indications for GI endoscopy:

1 Urgent endoscopy
2 Elective/diagnostic endoscopy
3 Therapeutic endoscopy

Urgent endoscopy	Elective diagnostic endoscopy	Therapeutic endoscopy
GI bleeding Caustic ingestion Foreign body ingestion	Recurrent upper abdominal pain Dysphagia/odynophagia Vomiting Weight loss Anemia/occult blood loss Malabsorptive chronic diarrhea Radiographic evidence of mucosal lesions Evidence of mass lesion by upper GI series Familial polyposis or Peutz–Jeghers syndrome	Foreign body removal Sclerotherapy Placement of gastrostomy tube Electrophotocoagulation Polypectomy Dilatation of esophageal stricture Pneumodilatation of achalasia Botox injection

Table 5.1 Indications for pediatric upper GI endoscopy.

Specific indications for pediatric esophagogastroduodenoscopy (EGD) are listed in Table 5.1.

The spectrum of common indications for EGD varies between the different age-groups (Table 5.2). The difference in age-related indications simply reflects the age-related variations of GI pathology.

Bleeding

Upper GI bleeding in children is probably the most serious condition requiring endoscopy. The goal of upper GI endoscopy in children with melena or hematemesis is to define the source of bleeding and to perform therapeutic procedures such as sclerotherapy, electro/photocoagulation, and injection

Neonates and noncrawling infants	Crawling infants and toddlers	School-age children and teenagers
Hematemesis	Recurrent vomiting	Recurrent epigastric pain
Melena	Hemoccult-positive stool	Weight loss
Obstructive apnea	Foreign bodies	Symptoms of gastroesophageal reflux disease
Recurrent vomiting	Caustic ingestion	Iron deficiency anemia
Chronic diarrhea	Chronic diarrhea	Chronic diarrhea
	Hematemesis	Hematemesis
	Recurrent abdominal pain	Caustic ingestion
		Foreign bodies

Table 5.2 Age-related indications for upper GI endoscopy.

of vasoconstrictive agents or constrictive devices, if necessary. The same questions are always raised in such circumstances. Is the patient stable? Does the child have upper GI bleeding or epistaxis? What is the cause of bleeding? What is the optimal time for endoscopy?

A good history, quick assessment of skin, tissue perfusion, pulse, blood pressure, presence of old or fresh blood at the nostrils or oropharynx, and level of consciousness provide enough information to answer the first two questions.

Good venous access has to be established simultaneously for adequate volume resuscitation with normal saline alone or 5% albumin solution until blood is available. Blood for type and screen has to be sent to the blood bank. Repeated measurements of pulse and blood pressure are rough but useful signs of appropriate fluid resuscitation.

The patient with recurrent hematemesis is at risk for aspiration, and protection of the airways is an important component of the therapy. This may be achieved by elevation of the head, repeated aspiration of oropharyngeal contents, and/or intubation in case the patient is unconscious or has significant blood gas disturbances.

Gastric lavage is a routine procedure, which may help in assessment of ongoing bleeding, but it can be misleading if the source of bleeding is within the duodenum or the proximal small bowel. It should be performed with room-temperature saline through a large-diameter orogastric tube until the returned fluid is clear or bleeding significantly diminishes. It usually takes about 10 minutes to assess the effectiveness of the gastric lavage. Most of the time, the bleeding will stop spontaneously. In this case, endoscopy provides the best diagnostic yield if it is performed as soon as the patient is stable.

If gastric lavage is ineffective or the patient's blood volume has been replaced in less than 1 hour, the role of emergency endoscopy is questionable. Sometimes it is impossible to find the source of severe bleeding precisely, but if, for example, fresh blood is seen coming back into the stomach through the pylorus, it provides important information about the possible source of bleeding.

In case of bleeding from an ulcer, endoscopy may predict the risk of recurrence based upon location and appearance: pigmented spots (Fig. 5.37), an adherent clot (Fig. 5.38), a visible vessel or blood spurting, and location of ulcer on the posterior wall of the duodenum are important prognostic factors.

It also helps to make the best choice of treatment regarding the detected source of bleeding (e.g., hemorrhagic gastritis versus secondary or primary/peptic ulcer or portal hypertension).

The causes of bleeding vary depending upon the age of the patient (Table 5.3).

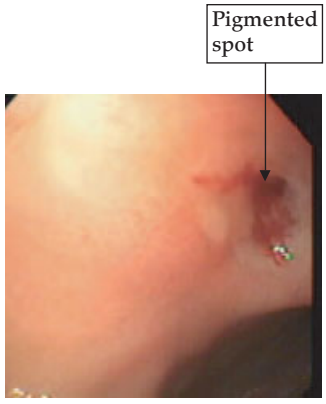

Fig. 5.37 Pigmented spot. This is the sign of the recent bleeding with low probability of recurrent bleeding.

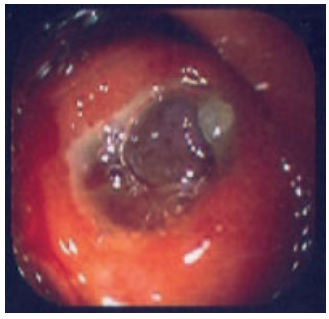

Fig. 5.38 An adherent clot. The discovery of this stigmata of recent bleeding warrant the higher risk of recurrent bleeding and required endoscopic hemostasis and close observation.

Age	Upper GI bleeding	Low GI bleeding
Neonates (0–30 days)	Swallowed maternal blood Hemorrhagic disease of the newborn Stress ulcers/sepsis Hemorrhagic gastritis	Necrotizing enterocolitis Midgut volvulus Anal fissure Hirschsprung's disease Vascular malformation
Infants (30 days to 6 mo)	Cow milk or soy-protein allergy Esophagitis Mallory–Weiss tear Portal hypertension	Anal fissure Allergic proctitis or enterocolitis Nodular lymphoid hyperplasia Intussusception
Infants and children (6 mo to 6 yr)	Epistaxis Esophagitis Portal hypertension Drug-induced ulcers Gastritis	Anal fissures Intussusception Meckel's diverticulum Nodular lymphoid hyperplasia Polyps Infectious colitis Hemolytic uremic syndrome Henoch–Schonlein purpura
Children and teenagers (7–18 yr)	Epistaxis Drug-induced gastropathy and ulcers Peptic ulcer Esophagitis Gastritis Portal hypertension Crohn's disease	Infectious colitis Ulcerative colitis Crohn's disease Polyps Polyposis Hemorrhoids

Table 5.3 Common causes of GI bleeding in children.

In neonates the most common endoscopic findings are gastritis alone or in combination with esophagitis, and/or secondary gastric or duodenal ulcers due to neonatal stress, sepsis, or hypoxia. The other possible but rare cause of hematemesis in neonates is cow's milk intolerance.

In infants and young children the spectrum of diseases causing hematemesis or melena is broader: acute drug-induced gastritis or duodenitis; a variety of secondary ulcerations due to sepsis, or increased intracranial pressure and stress from major surgery; reflex esophagitis; Mallory–Weiss tear; esophageal varices; opportunistic infections in immunocompromised patients, etc.

The frequency of aspirin-induced gastric and duodenal lesions in children is substantially less now than in the past. However, they still do happen because many over-the-counter "cold medications" contain salicylates. Nonsteroidal anti-inflammatory (NSAID) drugs may also cause gastritis and ulcers.

Two types of lesions are often observed. Type 1: acute gastritis with multiple separate or confluent spots of erythema, petechiae, and erosions with red rim. Type 2: gastric and occasionally duodenal punch-out ulcers surrounded by pink or patchy erythematous mucosa. NSAIDs can induce similar lesions.

The other type of drug-induced lesion is hemorrhagic gastritis. The hallmark of hemorrhagic gastritis is subepithelial hemorrhages, with or without mucosal edema. It may be either localized or widespread. In severe lesions a large area of gastric surface may be actively bleeding.

Although peptic ulcer disease is a relatively rare issue in pediatric patients, it comprises at least half of the cases of bleeding from the upper GI tract in school-age children. The majority of bleeding ulcers are located in the duodenal bulb (Fig. 5.39). In general, most episodes of bleeding (at least 80%) cease spontaneously, but if the bleeding is arterial the incidence of recurrent episodes will be increased and may potentially become life-threatening.

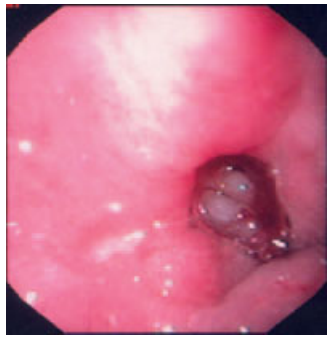

Fig. 5.39 Active bleeding from the duodenal ulcer.

Severe bleeding from the upper GI tract usually manifests with hemodynamic instability, hematemesis, failure to clear gastric aspirate, melena and occasional hematochezia. In these circumstances an urgent endoscopy is necessary as soon as the patient becomes stable after volume resuscitation.

If blood spurting or a visible vessel has been found, the risk of recurrent bleeding is high even after an initially successful endoscopic hemostasis. These patients require careful observation and treatment with high dose of proton pump inhibitors intravenously. The most frequent recurrence of bleeding occurs during the 3 days following the initial loss of blood. If an ulcer has a clear base or pigmented spot, the risk of further bleeding is minimal and therapeutic endoscopy is not indicated.

Chronic recurrent abdominal pain is the most common indication for EGD, simply because it exists in 10–17% of children between 5 and 14 years. According to current knowledge, more than 90% of children with this complaint have "functional" abdominal pain. If the clinical scenario is indicative for organic causes of pain, EGD with biopsy is the best tool for diagnosis of peptic ulcer, gastritis, duodenitis, or other mucosal diseases.

Chronic peptic ulcers

Peptic ulcer disease tends to occur in school-age children (predominantly in boys). In most cases, primary ulcers are located in the duodenal bulb. The active stage of peptic ulcer disease usually manifests by significant spasm and rigidity of the duodenal bulb (Fig. 5.40). These conditions may be aggravated by scarring from previous relapses or by manipulations with the endoscope per se. In such circumstances maximal attention has to be paid to indirect endoscopic signs such as convergence of mucosal folds, severe erythema, or edema of the duodenal mucosa. If necessary, glucagon may be used to reduce spasm of the duodenum.

It is not unusual to find multiple or "kissing" duodenal ulcers in children with peptic disease. That is why a thorough

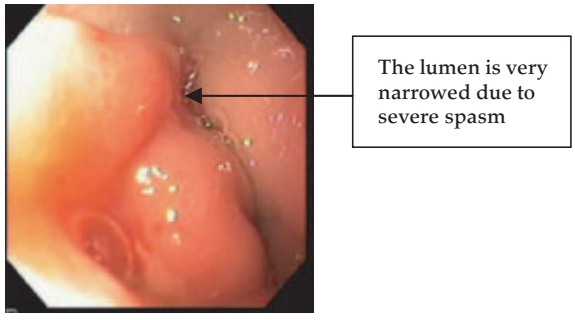

Fig. 5.40 Severe spasm of the duodenal bulb induced by an active ulcer.

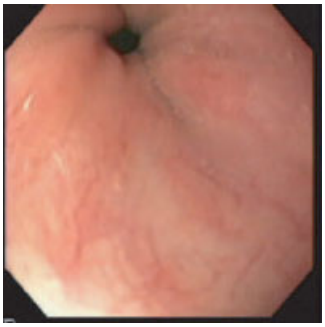

Fig. 5.41 Normal endoscopic appearance of the esophageal mucosa. A biopsy is necessary to confirm a normal morphology.

examination of the opposite wall has to be carried out if an ulcer or a scar has been detected.

Gastroesophageal reflux disease

In children with gastroesophageal reflux disease, upper GI endoscopy is indicated if symptoms persist in spite of standard therapy or if esophagitis or its complication is suspected. Endoscopic classification of reflux esophagitis in children consists of five types of findings or grades from 0 to 4.

Grade 0 represents an endoscopically normal esophageal mucosa (Fig. 5.41). Grade 1 confines focal or circumferential erythema, edema, and loss of vascular pattern or exudate. Mild circumferential erythema of the distal esophageal mucosa right above the Z-line is normal for neonates and should not be associated with grade-1 lesions. Endoscopic descriptions of esophageal mucosa in children with grade-0 and -1 lesions are quite subjective and require a morphological verification. Two mucosal biopsies are recommended at least 2 cm above the Z-line. Grade-2 mucosal changes are associated with noncircumferential lineal erosions (Fig. 5.42). More advanced circumferential lesions constitute grade-3 esophagitis (Fig. 5.43). Grade 4 or

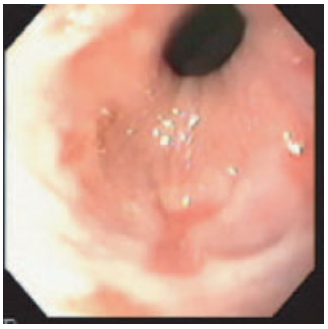

Fig. 5.42 Grade 2 endoscopic findings consistent with esophagitis. The hallmark of grade 2 lesions is noncircumferential lineal erosions.

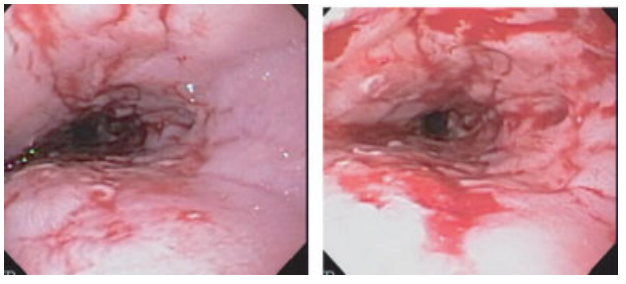

Fig. 5.43 Grade 3 endoscopic findings. Circumferential lesions including lineal and/or other type of erosions.

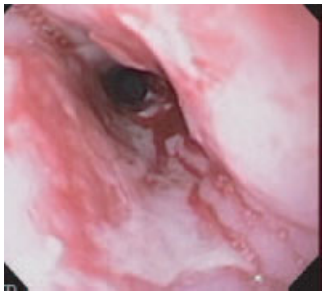

Fig. 5.44 Esophageal ulcer as one of the element of endoscopic classification consistent with grade 4 esophagitis.

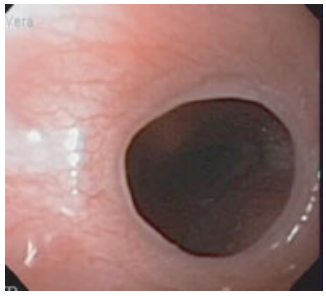

Fig. 5.45 Esophageal stricture. Esophageal stricture due to reflux esophagitis usually appears as a short, white or silver colored, crescent-like or ring-type scar in the distal esophagus surrounded by pale or inflamed mucosa.

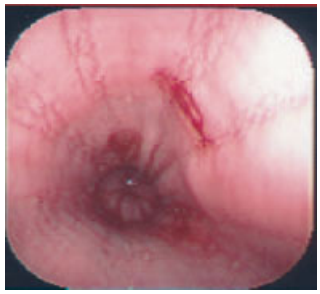

Fig. 5.46 The "vertical line" sign. This endoscopic finding is suspicious for eosinophilic esophagitis. The definitive diagnosis is made on the basis of 20 or more eosinophils per high-power field on light microscopy.

the most severe form of reflux esophagitis presents with ulcers (Fig. 5.44) or stricture (Fig. 5.45). Multiple circumferential stepwise biopsies are indicated for children with grade 2–4 lesions in order to rule out BE. This classification reflects the fact that EGD alone has low sensitivity and specificity for diagnosis of nonerosive forms of reflux esophagitis in children. Thus, it is imperative to perform esophageal biopsy for histological confirmation of esophagitis in pediatric patients, even in children with normal appearance of esophageal mucosa. A big advantage of EGD is an ability to assess the severity and extent of esophageal lesions, perform a target biopsy, and carry out a complex assessment of entire upper GI tract, which allows diagnosing synchronous lesions in the stomach and duodenum.

During the last decade, a specific type of esophagitis unresponsive to a standard antireflux therapy has been described in children and then in adults. The presence of at least 20 eosinophils per high-power field as the main diagnostic criterion gave the name of this condition: eosinophilic esophagitis. It could be suspected endoscopically if the "vertical line" sign (Fig. 5.46) or lesions in the proximal esophagus are present.

Stricture due to reflux esophagitis in children is usually short and is located in the distal esophagus. Uncomplicated esophageal stricture appears as white, crescent-like scars surrounded by pale mucosa or inflamed, edematous narrowing of the lumen. Esophageal stricture becomes asymmetrical if complicated by a coexisting ulcer (Fig. 5.47). Schatzki's ring should be considered if the narrowing is short, located just above the Z-line, and is surrounded by normal-appearing esophageal mucosa (Fig. 5.48). It could be missed during endoscopy. An esophagram with barium is indicated in children with dysphagia of solid food and negative upper GI endoscopy.

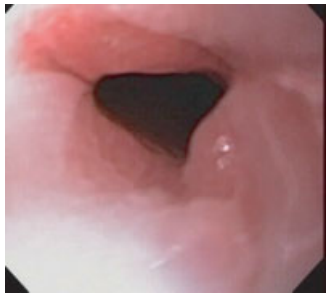

Fig. 5.47 Stricture of the middle esophagus in the child with repaired tracheoesophageal fistula and severe gastroesophageal reflux and failed fundoplication. The irregular shape of the stricture is secondary to significant esophagitis.

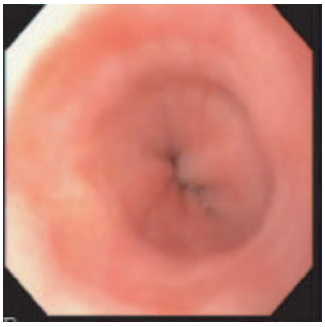

Fig. 5.48 Schatzki's ring. Type B or mucosal rings are more common entity, which is associated with dysphagia. These short lesions within the 2 cm of the distal esophagus can be missed on endoscopy. Care should be taken to minimize insufflation and secondary overdistention of the distal esophagus to avoid false negative results. The esophagram may be very useful in children with dysphagia and negative endoscopy.

On rare occasions, a severe stenosis of the middle esophagus may be caused by tracheobronchial remnants. This type of stenosis is usually symmetrical but more elongated compared with stricture secondary to esophagitis. Translucent cartilages and absence of inflammation assist with the diagnosis.

BE is rare in children. However, it has to be kept in mind because of its malignant potential. Ten cases of esophageal cancer related to BE in children have been already described.

By definition, BE is an extension of columnar epithelium with specialized goblet cells that undergo metaplasia and grow into the tubular esophagus. An esophagogram does not have diagnostic value because there is no specific radiological sign of BE. Blind suction biopsy directed by esophageal manometry has been used in the past, but had significant sampling error and could not be used for correct histological mapping. Currently, endoscopy with multiple biopsies is the gold standard for diagnosis of BE. The role of endoscopy is to identify abnormal areas of the esophageal mucosa such as tongue-like protrusions from the Z-line toward the thoracic esophagus (Figs. 5.49 and 5.50), or, in rare cases, separate islands of pink mucosa or ulcers surrounded by patches of esophageal mucosa.

The diagnosis of BE requires esophageal biopsies from different levels above Z-line. At least two samples should be taken from each level. The tissue samples should be stained with Alcian blue at pH 2.5 to identify goblet cell metaplasia, which is

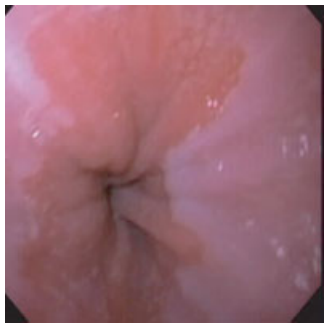

Fig. 5.49 Barrett's esophagus. Tongue-like lesions spreading from the Z-line upward.

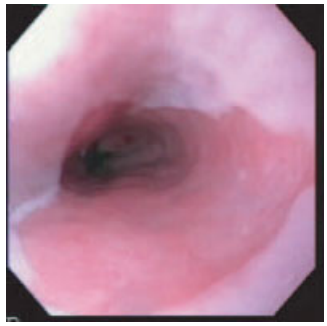

Fig. 5.50 Barrett's esophagus. Circumferential lesions can imitate displacement of the Z-line and create a false impression of hiatal hernia. The random biopsies with four biopsy specimens taken at least every 1–2 cm of esophageal mucosa with additional biopsy specimens taken if any mucosal abnormality is recommended.

diagnostic. If only cardiac gland metaplasia is found, BE has to be suspected and endoscopy with biopsy should be repeated in 1 year. Endoscopic surveillance at 3–4-year intervals have been proposed for children over 10 years of age with diagnosed BE but no evidence of dysphagia.

Endoscopy is also helpful in the diagnosis of the hiatal hernia. Endoscopic sign of hiatal hernia is cephalad displacement of proximal margin of the gastric mucosal folds by 2 cm or more, above the diaphragmatic notch. The diagnosis requires precise recognition of the diaphragmatic notch by respiratory movements – closure during inspiration and opening with expiration. It is not always easy in the deeply sedated child. Observation of the cardia with retroflexion technique helps to locate the diaphragmatic notch and clarify the relationship with the Z-line.

Infectious esophagitis is a frequent cause of dysphagia and odynophagia in immunocompromised children. The most common types of infectious esophagitis are caused by candida, cytomegalovirus (CMV), or herpes simplex virus (HSV). Endoscopy with brush cytology and/or biopsy are the most reliable diagnostic methods.

Candida esophagitis may present with erythematous mucosa covered by scattered or confluent white, cream-colored, thick plaques, with greatest density in the distal esophagus (Fig. 5.51).

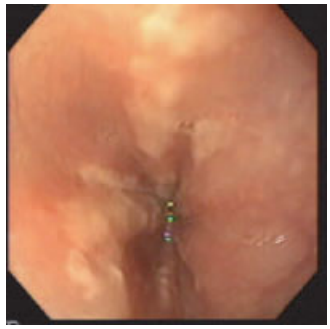

Fig. 5.51 Candida esophagitis. Characteristic white, thick plaques in the distal esophagus.

Shallow serpiginous ulcerations surrounded by normal mucosa are often seen in CMV esophagitis. Histological marks of CMV are basophilic, intracellular inclusions, a clear halo surrounding the nucleus, and the presence of multiple smaller periodic acid-Schiff positive intracytoplasmic inclusions.

HSV is the most common cause of herpetic esophagitis. The disease may be started with herpetic lesion(s) on the lips or buccal mucosa, followed by odynophagia or dysphagia.

The endosopic hallmark of herpetic esophagitis is aphthoid-like ulcers with a raised erythematous margin and gray or yellowish base. These ulcers are typically seen in the middle or upper esophagus. In advanced disease, diffuse involvement of mucosa with confluent ulcers, exudate, or friability may occur (Fig. 5.52).

To obtain adequate tissue samples with the replicating virus, the biopsy should be taken from the margin of the ulcer. Multinucleate giant cells and ballooning of the cells, prominent eosinophilic intranuclear “ground glass” inclusions, and chromatin margination are diagnostic.

Caustic ingestion

Despite precautions, corrosive injuries still occur, usually as tragic accidents. These incidents take place mostly in young children under 5 years or during suicide attempts by teenagers.

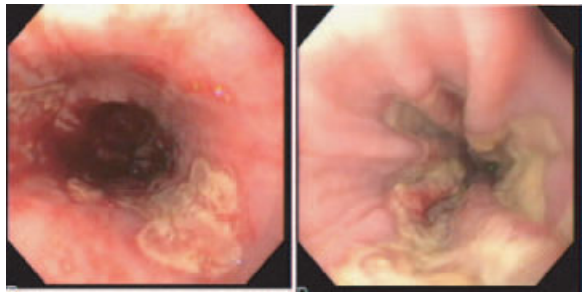

Fig. 5.52 Herpetic esophagitis. The triad such as erythema, aphthoid-like ulcers, and exudates is suggestive of viral esophagitis. The presence of the multinucleated giant cells with prominent eosinophilic intranuclear inclusions and chromatin margination is diagnostic.

Lye ingestion induces severe injuries primarily in the esophagus, although strong acid may create more diffuse lesions including the stomach or duodenum. Sodium hydroxide in different preparations induces rapid liquefaction necrosis with deep (even full-thickness) injuries. Respiratory distress, esophageal perforation, or periesophageal inflammation with subsequent mediastinitis and peritonitis are the most serious short-term complications of caustic ingestion.

Immediate and long-term outcomes are directly related to the degree of burn. The absence of visible lesions on the lips and oral or pharyngeal mucosa does not correlate with the absence of esophageal or gastric injuries. As soon as the patient is stable, upper GI endoscopy has to be done under general anesthesia, especially if the patient was agitated, drooling, tachypneic, or hemodynamically unstable on arrival. In superficial involvement, the esophageal mucosa appears erythematous or edematous with minimal or no mucosal peeling.

If an injury is more extensive, the sloughing of mucosa is more extensive and leaves behind hemorrhagic exudates, islands of mucosal debris, or ulcerations. The hallmark of severe esophageal burns is the presence of an eschar or deep ulcers. It is not uncommon that in severe burns the esophagus is difficult to assess, because of obliteration of the lumen as the result of severe spasm and edema of deeply injured wall. Any attempt at forceful maneuver or insufflation has to be avoided. Patients with no visible mucosal lesions may be discharged. The rest of the patients with caustic ingestions have to be hospitalized for at least 24–48 hours in case of mild injury.

Withholding of oral feeding, parenteral nutritional support, broad-spectrum antibiotics, and steroids are the conventional therapies for patients with moderate or severe burns. Nasogastric intubation has also been used with apparent success.

Gastritis

During endoscopic examination of the stomach, several mucosal patterns may be found: normal appearing gastric mucosa which is pink and smooth with visible vessels more prominent in proximal areas; focal or diffuse erythema, edema, erosions, nodularity, and petechiae. The clinical scenario and histological data determine the value of these findings.

For instance, if the clinical history is positive for salicylates or other NSAID ingestion, the finding of mucosal edema, petechiae, or erosions are diagnostic, although gastric erosions have been found in asymptomatic volunteers. Because there is no strong correlation between endoscopic and histological changes of gastric mucosa in terms of chronic gastritis, any endoscopically suspicious areas have to be verified by target biopsies. This is especially important for detection of HP, as it may substantially change the approach to the therapy. Although nodularity of the antral mucosa has been found in about 50% of HP-colonized children, this endoscopic sign (Fig. 5.53) cannot substitute for histological identification of S-shaped bacteria on the surface of gastric mucosa (stained by Warthin Starry or Giemsa technique).

A finding of gastric erosions also has a different diagnostic value (Fig. 5.54). In immunocompromised children it could be the sign of viral gastritis. In CMV gastritis, the inflammation usually involves a submucosal layer of the stomach. Endoscopically, it may appear as an irregular, nodular gastric surface with shallow ulceration or apparent gastric ulcer. If inflammation occurs in the antrum or prepyloric area, it may cause gastric outlet obstruction and occasionally can mimic a submucosal tumor (Fig. 5.55). The finding of intranuclear inclusions and positive tissue culture are diagnostic. Herpetic gastritis may be found in children with HIV infection or post bone marrow or liver transplantation. EGD shows small shallow ulcers with whitish exudate at the basis. Ulcers may coalesce and be surrounded by

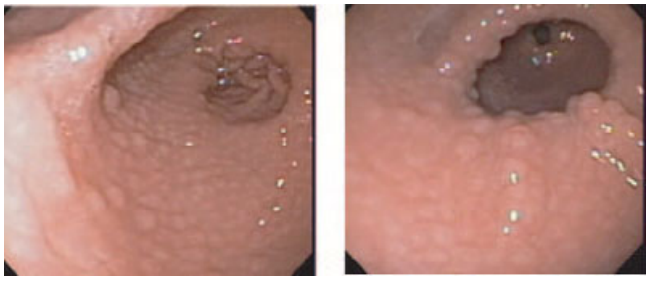

Fig. 5.53 HP gastritis. The most common endoscopic sign of HP gastritis is antral or diffuse nodularity.

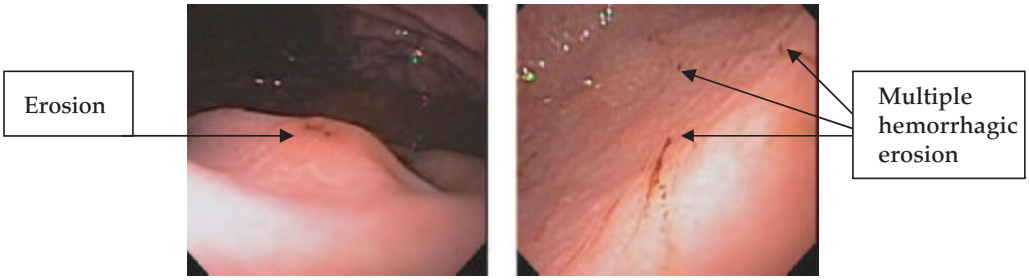

Fig. 5.54 Gastric erosions. Different types of gastric erosions can be found in children. They are not specific. The biopsy is required to verify the underlying pathology.

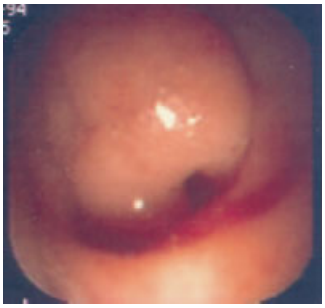

Fig. 5.55 CMV gastritis. The intense inflammation in the prepyloric antrum may simulate a submucosal mass effect.

erythematous mucosa. Biopsy from the margin of the ulcer and a tissue culture are necessary to confirm herpetic infection.

Pediatric hypertrophic gastropathy or Menetrier's disease

Menetrier's disease is a rare cause of protein-losing enteropathy in children, but over the last decade the number of published cases has doubled. The exact etiology of the disease is unknown, but currently the role of CMV infection is the focus of investigation.

In Menetrier's disease, EGD shows an enormous amount of gelatinous mucus in the stomach, giant gastric rugae in the fundus or gastric body that remain unchanged despite vigorous insufflation, and edematous mucosa often with shallow ulceration. Histological signs of Menetrier's disease are hypertrophic and dilated gastric glands filled with mucus, basilar cystic changes, and mixed infiltration of lamina propria with neutrophils, lymphocytes, eosinophils, and occasional plasma cells. Unique features of Menetrier's disease in children are reversible endoscopic and histological changes in the gastric mucosa and the disappearance of clinical symptoms with adequate therapy in the majority of patients.

Crohn's disease

Current data suggest that involvement of the upper GI tract in pediatric patients with Crohn's disease occurs more often than previously thought. The rate of positive findings of noncaseating granuloma in the stomach or duodenum in unselected patients who underwent EGD was higher than in selected patients with presumptive symptoms of upper GI tract involvement: dysphagia, aphthoid lesions in the mouth, epigastric pain, weight loss, nausea, and vomiting or blood loss. In addition, 11.4–29% of

patients with onset of Crohn's disease may have an isolated inflammation of the stomach and duodenum. Thus, routine use of EGD in patients with suspected Crohn's disease is indicated.

Endoscopic findings of skipped lesions such as aphthous ulcers, nodularity, thickening of mucosal folds, and rigidity or narrowing of the antral portion of the stomach or proximal duodenum are suggestive of Crohn's disease. The serpiginous or longitudinal ulcers are rarely seen in children, but if found may be helpful to distinguish it from peptic disease.

The goal of histological evaluation of the stomach and the duodenum in children with suspected Crohn's disease is finding noncaseating granulomas, which occur in 30–40% of cases. There is no significant difference in the detection of granulomas in biopsies taken from endoscopically normal or abnormal areas of gastric or duodenal mucosa. That is why multiple samples of endoscopically normal or altered mucosa have to be obtained to increase the diagnostic value of the procedure.

The absence of noncaseating granulomas does not rule out Crohn's disease. The presence of focal inflammation with "crypt abscess," focal lymphoid aggregates, and fibrosis may be diagnostic in children with suggestive history and confirmed Crohn's disease in the small or large intestine.

Hypertrophic pyloric stenosis

In typical cases hypertrophic pyloric stenosis (HPS) can be easily diagnosed by clinical symptoms, physical examination, and presence of metabolic alkalosis. Palpation of a pyloric mass is conclusive and does not require further investigation.

If a pyloric mass is not detected or palpation is equivocal, an ultrasonic scan (US) is the procedure of choice. Despite the high accuracy of US, false negative results have been described (especially in clinically equivocal cases). In this situation, an upper GI endoscopy may be a good alternative to an upper GI series. The advantage of the former method is the ability to directly assess the pylorus and coexistent conditions as esophagitis, hiatal hernia, or gastritis that may interfere with the postoperative recovery. The obvious disadvantages are invasiveness and a high cost, compared with sonography or upper GI series. But the absence of serious complications and exposure to radiation, as well as an earlier diagnosis with subsequent reduction of a duration and total cost of hospitalization, may compensate for any initial expenses.

The most reliable endoscopic sign of HPS is bulging of the tight pylorus into the prepyloric antrum with the mucosal folds directed toward the depressed center of the pyloric channel (Fig. 5.56). In the early course of the disease, when a muscle hypertrophy is not so "stiff" and allows some excursion, a pyloric

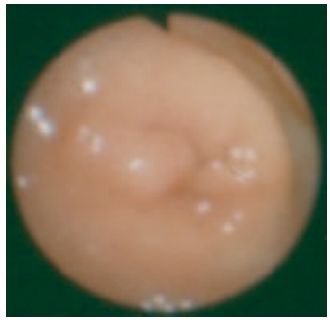

Fig. 5.56 HPS. Bulging pylorus is reliable endoscopic sign of infantile HPS.

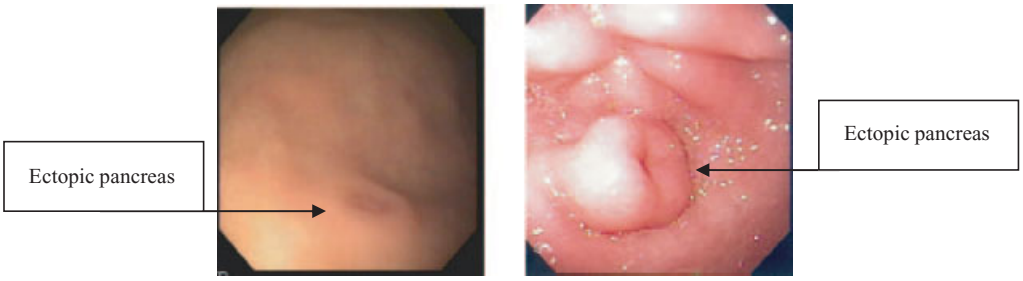

Fig. 5.57 Ectopic pancreas in the stomach. The "doughnut" shape small lesion is located on the greater curvature of the antrum. It is usually an incidental finding during EGD.

opening less than 5 mm, with elongation and irregularity of the pyloric channel, helps to make a correct diagnosis.

Inability to advance the endoscope beyond the pylorus without the other endoscopic signs of HPS is not a reliable endoscopic sign and may lead to false positive results. Concomitant findings of esophagitis or gastritis may help to predict and prevent such complications as recurrent vomiting or bleeding in the early postoperative period.

Gastric tumors

Gastric tumors in children are rare and usually benign. In the majority of cases they are either ectopic pancreas or hyperplastic polyps.

Ectopic pancreas is often asymptomatic and, in most children, is an incidental finding during an endoscopy or an upper GI series. True prevalence of this disease in children is unknown. In the stomach, ectopic pancreas is located on the greater curvature of the antrum and appears as a small, less than 1 cm, dome-shaped lesion with a central depression (Fig. 5.57). It is usually covered by unchanged gastric mucosa. Sometimes the lesions may be less protruded toward the gastric lumen and reminds one of a "bagel" or "doughnut." A biopsy is not indicated, as an ectopic tissue arises from the submucosal or subserosal layers.

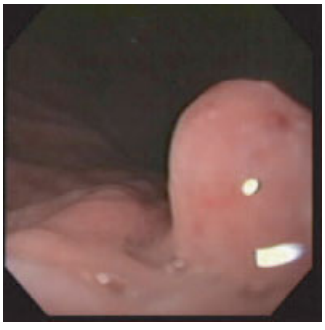

Fig. 5.58 Inflammatory polyp of the enlarged fold of the cardia.

A small hyperplastic gastric polyp is usually asymptomatic unless it is located near the pylorus, causing gastric outlet obstruction or anemia due to recurrent prolapse into the duodenal bulb. More often a hyperplastic polyp in children is single, sessile, less than 1 cm in length, and is located in the antrum or the proximal aspect of the enlarged fold of the cardia (Fig. 5.58). It is not considered as premalignant. Endoscopic polypectomy is indicated only if the patient is symptomatic or if the polyp is bigger than 1 cm and ulcerated. Endoscopic surveillance after polypectomy is unnecessary if the diagnosis of hyperplastic polyps is confirmed histologically.

The presence of multiple gastric polyps is the sign of polyposis syndrome. In children with Gardner's syndrome, small sessile polyps are usually located in the gastric fundus. In generalized juvenile polyposis or Peutz–Jeghers syndrome, gastric polyps may be dispersed throughout the stomach (Fig. 5.59). The polyps could be removed in one or several endoscopic sessions. Sometimes the number of polyps precludes a complete eradication. In these cases, the largest polyps should be removed. In children with Peutz–Jeghers syndrome, gastric polyps coexist with multiple hamartomas in the duodenum or proximal jejunum (Fig. 5.60). Some of these polyps could be quite big, reaching 4 or 5 cm. Such polyps are the common cause of chronic small bowel intussusceptions and the leading cause of intermittent abdominal pain. Polypectomy of these hamartomas is a technically challenging procedure and carries a high risk of severe arterial bleeding and perforation.

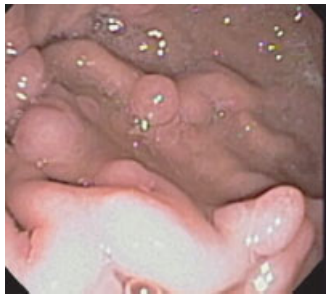

Fig. 5.59 Multiple hamartomas of the stomach in a patient with Peutz–Jeghers syndrome. Annual surveillance endoscopy with multiple biopsies and polypectomy of the largest polyps is indicated.

Malignant tumors of the stomach account for only 5% or less of all malignant neoplasm in children. The most common malignant gastric tumors in children are non-Hodgkin's or Burkitt's lymphoma or gastric involvement in lymphoproliferative disorder after solid organs or bone marrow transplantation (Figs. 5.61–5.63).

Gastric bezoar must be included in differential diagnosis because it may simulate clinical symptoms of malignancy, especially if a palpable mass or anemia is present. Usually these symptoms are related to trichobezoars that have indolent courses and may occupy virtually the whole stomach and proximal duodenum, causing irritation of the gastric mucosa, secondary gastric ulcers, and anemia. Such a bezoar has to be surgically removed, although an alternative treatment by extracorporeal shockwave lithotripsy in an 8-year-old child has been described.

Phytobezoars may be dissolved with Coca-Cola lavage or easily cut down by an endoscopic snare, for small fragments are able to pass through the gut.

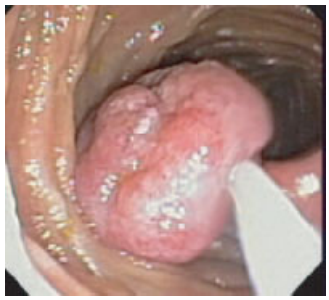

Fig. 5.60 Hamartoma in the duodenum. These lesions are usually multiple and require repeat polypectomies. The risk of complication is proportional to the size of the polyp. Surgery should be considered in patients with polyps of 4 cm or bigger to avoid severe bleeding or perforation.

Celiac sprue

Partial or total atrophy of the small bowel mucosa may be the end point of different pathological processes, including celiac sprue, giardiasis, cow's milk allergy, postinfectious inflammation, and immunodeficiency. It is not uncommon that clinical symptoms of these conditions overlap. Moreover, even celiac sprue, per se, has a variety of presentations, including monosymptomatic ones, such as anemia and short stature.

For more than three decades, jejunal capsule biopsy was the cornerstone for diagnosis of celiac sprue. But it is time-consuming, requires fluoroscopy, and has a certain failure rate. It

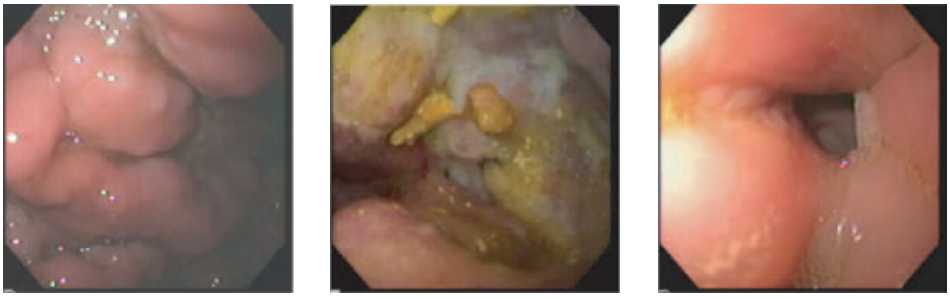

Fig. 5.61 Non-Hodgkin's lymphoma. Induration of the gastric wall and multiple deep ulcerations are always suspicious for malignancy. Left image: malignant infiltration of the gastric folds; middle image: ulcerated malignant mass; right image: malignant infiltration of the pylorus.

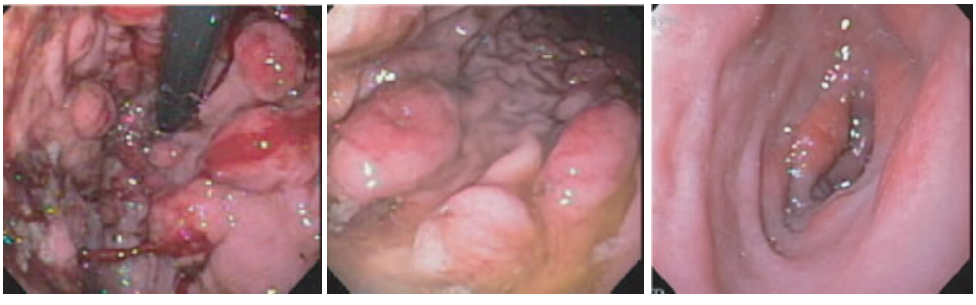

Fig. 5.62 Burkitt's lymphoma of the stomach and the small intestine. Loose teeth was the presenting symptom. EGD was performed to evaluate progressive weight loss, abdominal pain, and anemia. Multiple erythematous nodules with or without ulcerations and infiltration of the gastric wall were found. The diagnosis was confirmed morphologically by the gastric and bone marrow biopsies. Left picture: multiple ulcerated masses in the proximal stomach; middle picture: ulcerated masses along the greater curvature of the stomach; right picture: focal malignant infiltration of the duodenum.

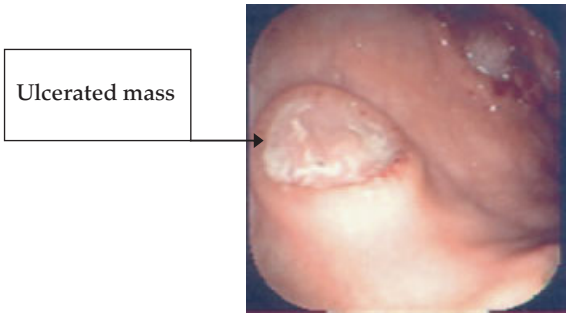

Fig. 5.63 Multiple ulcerated gastric mass in patient with lymphoproliferative disorder after liver transplantation.

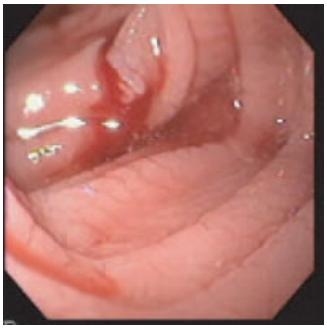

Fig. 5.64 Mosaic pattern of the duodenal mucosa in the child with untreated celiac sprue.

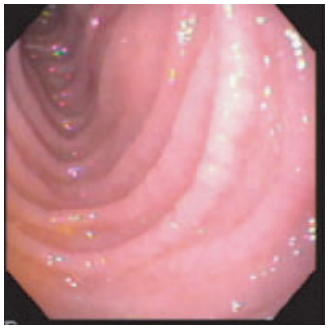

Fig. 5.65 Scalloping of the duodenal and/or jejunal folds. This endoscopic sign is more prominent in the distal duodenum or jejunum. An application of the vital stains such as methylene blue augments this mucosal pattern.

has been replaced by endoscopic biopsies in adults and children. Moreover, EGD may provide additional information about concomitant lesions in the upper GI tract, or accidentally discovers mucosal changes suggestive of celiac sprue in children with equivocal clinical scenarios. The major endoscopic findings of celiac sprue in children are mosaic pattern of the duodenal and jejunal mucosa and notched duodenal and jejunal folds or "scalloping" of the valvulae conniventes (Figs. 5.64 and 5.65).

In the active phase of celiac disease, the duodenal mucosa appears grayish, edematous, and mosaic, with an increased vascular pattern in the proximal duodenum. Duodenal folds are coarse, with a scalloped appearance more prominent on their edges. Mucosa between the duodenal folds has a mosaic or honeycomb pattern. These endoscopic signs are usually more prominent in the distal duodenum or proximal jejunum. Although duodenal or jejunal mucosa in celiac sprue patients is not friable, it bleeds more intensively than in nonspecific duodenitis after the biopsy (but not to the degree of significant hemorrhage).

The final diagnosis of celiac sprue is histological. At least four biopsies from the distal portion of duodenum are required. All specimens have to be properly oriented for correct assessment of villi architecture.

The mucosa typically returns to normal within 6 months in pediatric patients on a strict gluten-free diet. In noncompliant children, especially adolescents, mucosal atrophy may be clinically silent.

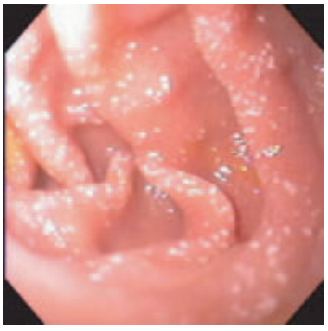

Fig. 5.66 Multiple whitish spots in the second and the third portion of the duodenum. This represents dilated lacteals. This endoscopic image is not specific for intestinal lymphangiectasia. Clinical correlation is a key for correct interpretation.

Intestinal lymphangiectasia

It is not uncommon to find scattered whitish spots in the second or third portion of the duodenum during routine upper GI endoscopy in children (Fig. 5.66).

These lesions represent dilated lacteals extending up into the small bowel villi. They may or may not be clinically relevant. Since the original description of these lesions as a sign of intestinal lymphangiectasia, it has been established that the same endoscopic and histological picture might represent functional lymphangiectasia or even the early stage of fat absorption. Thus, an endoscopic finding of white scattered spots in the distal duodenum or proximal jejunum which are not flushed out, white villi, or chylous material covering the mucosa should be correlated to the clinical picture, to establish their clinical significance.

In case of intestinal lymphangiectasia, the majority of patients suffer from chronic diarrhea, edema, lymphocytopenia, and abnormal fecal fat excretion. Additional signs such as failure to thrive, susceptibility to infection due to intestinal losses of immunoglobulins and intestinal sequestration of lymphocytes, chylous effusion (both pleural and/or peritoneal), abdominal swelling, and hypocalcemia have been described.

Although endoscopic and histological findings are present in most patients, in some cases they could be absent at initial endoscopy and biopsy. If primary or secondary intestinal lymphangiectasia is suspected clinically, but EGD with small bowel biopsy is normal or equivocal, a repeat EGD with multiple target biopsies after a fat-loading meal has been found to be very effective. The other reason to perform multiple biopsies is to avoid false negative results due to possible patchy distribution of the disease in the duodenum or jejunum.

PUSH ENTEROSCOPY/JEJUNOSCOPY

In the era of capsule endoscopy, push enteroscopy has lost its leading role in diagnosis of small bowel pathology, but it is still a procedure of choice for nonsurgical treatment of small bowel lesions.

Indications:

- Occult GI bleeding
- Hamartomas of the small bowel in chidren with Peutz–Jeghers syndrome
- Intraoperative small bowel enteroscopy

Two types of endoscopes are suitable for push jejunoscopy:

- Pediatric panendoscope is optimal for children younger than 12 years.
- Pediatric colonoscope is the best for teenagers.

Technique

A standard pediatric panendoscope can be advanced into the proximal and occasionally into the middle jejunum. The average depth of exploration is 50 cm, ranging from 20 to 100 cm beyond the ligament of Treitz.

Preparation for enteroscopy is the same as for an upper GI endoscopy. Patient is placed in the left lateral position and sedated (see Chapter 4). The details of esophageal intubation are described in section on Technique of esophageal intubation. As the shaft is advanced into the stomach, it slides along the greater curvature. In order to progress toward pylorus, it should overcome an increasing resistance of the gastric wall. It leads to a distention of the stomach and a loop formation. When the tip is in the second portion of the duodenum, the resistance reaches the level that precludes further progress: pushing the shaft forward induces paradoxical movement of the duodenal lumen away from the tip. To overcome this problem, the shaft should be positioned along the lesser curvature as close as possible before or right after exploration of the duodenum.

The goal of the maneuver is to straighten the scope as much as possible to align the esophagus, stomach, and duodenum along a single axis (Fig. 5.67).

Once the tip is beyond the angularis, it is elevated sharply; the shaft is rotated clockwise by 30–45° and pulled back. This maneuver aims a loop reduction. During withdrawl phase, the shaft is moving toward the lesser curvature. At a certain point, the tip starts moving toward pylorus. If the shaft is angled and the torque is right, the prepyloric folds should appear in the upper part of the screen around the 12 o'clock direction. The tip is adjusted according to the direction of prepyloric folds. An additional withdrawal makes the pylorus visible and allows the tip to slip through it (Fig. 5.68). Immediate vigorous clockwise rotation facilitates advancement of the scope into the second portion

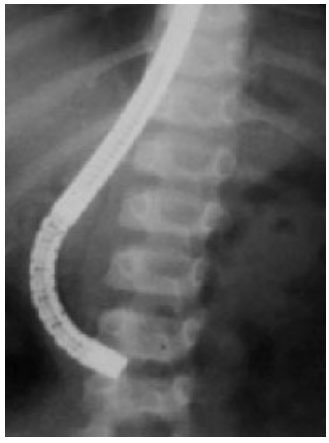

Fig. 5.67 The scope is positioned along the lesser curvature of the stomach while the tip is in the second portion of duodenum. The modified pull-and-twist technique prevents formation of a big gastric loop and optimal conditions for intubation of the duodenum and proximal jejunum.

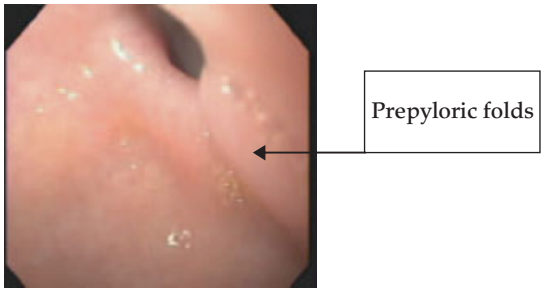

Fig. 5.68 The pylorus is in the upper pole of the screen. The tip is adjusted according to the direction of prepyloric folds.

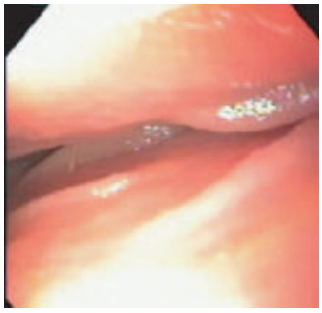

Fig. 5.69 The distal duodenum at the level of the ligament of Treitz. The lumen of this area may look like a slot or may disappear during transition into the proximal jejunum.

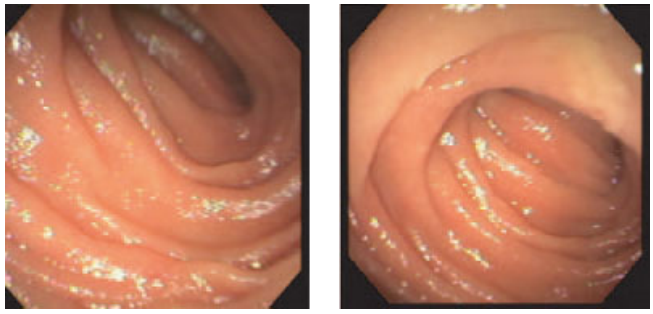

Fig. 5.70 The proximal jejunum. The prominent villous pattern and multiple mucosal folds with less space between the folds compared with the duodenum pattern are seen.

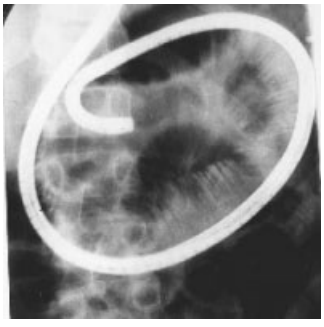

Fig. 5.71 The tip is in proximal jejunum, 20–30 cm below the level of a ligament of Treitz.

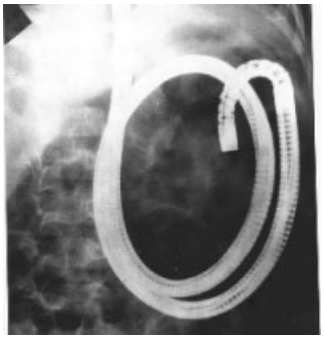

Fig. 5.72 The endoscope is in proximal jejunum at 80–100 cm.

of the duodenum. Continual rotation and gentle pulling back induce additional progress of the tip close to the ligament of Treitz (Fig. 5.69). If the duodenum is not successfully explored, pull-and-twist technique can be used (see section on Pull-and-twist technique). Minimal insufflation is an important element of the technique. Corkscrew maneuver is the key for sliding beyond the duodenojejunal junction successfully: the tip should be lowered to press down the underlying intestinal wall while the shaft is rotated clockwise. Additional to-and-fro movements help to create an optimal angle for the shaft to slip into the jejunum. At this moment, the lumen can disappear for few seconds and only sliding-by mucosa indicates the progress. To regain the lumen, the shaft is rotated clockwise and pulled back repetitively. The folds of the proximal jejunum are less prominent but are more frequent than in the duodenum. The villous pattern of mucosa is more prominent in the jejunum than in the duodenum (Fig. 5.70). Increased resistance and loop formation usually occur when the tip has advanced about 20–30 cm beyond the ligament of Treitz to the point where the jejunum starts deviating from left hypochondrium to the right (Fig. 5.71). Supine position is more useful for deeper jejunal exploration. After the patient is turned supine, a quick search for the loop is performed by palpation. If the loop is found, it should be reduced by clockwise or counterclockwise rotation, pulling the shaft back and applying manual pressure. Gentle pressure is applied to the epigastric area to prevent loop formation in the stomach before further attempt to advance the tip. Gentle push and torque facilitate the progress. Crescent-like lumen changes to oval and round with this maneuver. Repeated torque and pull-back movements drive the shaft in the deep jejunum up to 80–100 cm (Fig. 5.72).

More accurate estimation of the length of the explored jejunum is possible during the withdrawal phase by counting the number

of intestinal segments (each segment is defined by 7–10 cm of the bowel between two consecutive twisted areas). The procedure is fast, about 10–15 minutes, and does not require additional sedation. The procedure may be associated with mild pain or abdominal discomfort during early recovery phase. Serious complications such as perforation or bleeding have not been reported. Few petechiae in the jejunum and/or stomach can be seen.

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Practical Pediatric Gastrointestinal Endoscopy
George Gershman, Marvin Ament

6 Therapeutic Upper GI Endoscopy

BENIGN ESOPHAGEAL STRICTURE

Three chronic conditions are responsible for benign esophageal strictures in the majority of pediatric patients: severe reflux esophagitis including Barrett's esophagus, corrosive esophagitis, and esophageal atresia.

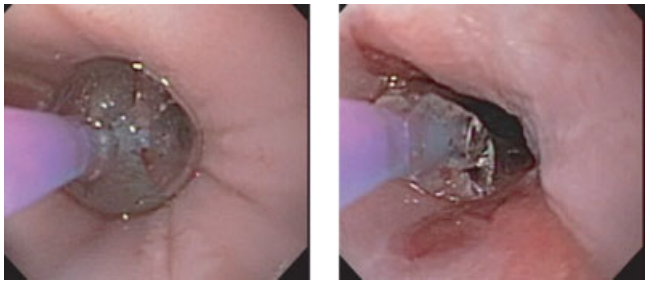
Strictures related to corrosive esophagitis are long and usually are not suitable for endoscopic dilatation. However, esophageal stricture secondary to reflux esophagitis or repaired esophageal atresia is short and can be treated endoscopically.

The technique of endoscopic dilation is quite simple. The procedure does not require fluoroscopy. The length of narrowed esophagus in children with a tight stricture is estimated by a prior esophagram.

Esophageal balloon dilators are available in three different sizes: 3, 5, and 8 cm in length. The short one is more vulnerable to slip from the stricture during dilation. A 5-cm dilator is the most convenient for positioning in pediatric patients. Each dilator can be distended with water to the designed diameter of 6–8–10 mm, 10–12–15 mm, and 12–15–18 mm with recommended pressure.

The procedure is started with proper sedation and intubation of the esophagus in the standard fashion. The size of the stricture is estimated visually. The length of the stricture is measured endoscopically or radiologically. Some corrections should be made for x-ray magnification and edema or spasm of adjacent esophagus. The diameter of the balloon chosen for the first dilation should be equal to or less than that of the stricture.

A guidewire is inserted into the biopsy channel and advanced 10–15 cm beyond the stricture to secure an intraluminal position of the balloon. The dilator is lubricated with silicone spray. Additional 1 or 2 ml of silicone oil can be injected into the biopsy channel. A dilator is threaded along the guidewire and slid through the stricture. The shaft is maneuvered to facilitate insertion of the dilator across the stricture with minimal resistance. Once the stricture is passed, the dilator is pulled back to place the middle portion of the balloon within the midpoint or waist of the stricture. The shaft is pulled back slightly to create an adequate distance between the top and the balloon to avoid damage during expansion with water (Fig. 6.1). The duration of the treatment session is 1 minute or less. Duration of dilation should not exceed 20–25 seconds with each dilator if a sequential dilation method is



(a) (b)

Fig. 6.1 Dilatation of the benign esophageal stricture. The dilator is placed across the stricture, filled with water (a), and then deflated (b).

chosen. Repeat treatments are necessary with 2–3-week intervals to dilate the esophagus to at least 10–12 mm wide at the level of the stricture. Dysphagia for solids and food impaction is usually resolved when the esophageal diameter is more than 10 mm.

Perforation is uncommon after balloon dilation of benign esophageal stricture. The reported frequency is less than 3%. This complication can occur when an inappropriate size of dilator or prolonged dilation time has been used. Medical treatment of perforation is very effective. It requires withholding of all oral feeding for 7–14 days, parenteral nutrition, and high dose of proton pump inhibitors to block acid secretion and broad-spectrum antibiotics to prevent mediastinitis.

PNEUMATIC DILATION IN ACHALASIA

Pneumatic dilation in achalasia is an effective and safe procedure if performed by experienced gastroenterologist. However, even in good hands, esophageal perforation can occur in about 6% of treated children.

It is quite unlikely that a practicing pediatric gastroenterologist will come across more than few children with achalasia due to the fact that the disease is rare (the reported incidence across western world ranges from 0.4 to 1.1 per 100,000 people) and usually becomes clearly apparent in teenagers. It may be reasonable to refer children with achalasia for pneumatic dilation to a tertiary center.

However, a pediatric gastroenterologist should be familiar with the effects of pneumatic stretching of lower esophageal sphincter (LES), principles of the technique, outcome, and post-procedure care.

First of all, pneumatic dilation works by rupturing some fibers of the circular muscle incorporated in LES. The magnitude

of muscle rupture is related to pressure, diameter, and time-depended deformation of the esophagus. Because of complexity of special configuration, different thickness of LES, and lack of experimental data from animal models, it is virtually impossible to calculate exact time and pressure to produce a desirable effect in a particular patient. It was proposed that a mucosal layer becomes responsible for integrity of esophageal wall after mechanical stretching and rupture of circular muscle fibers. Similar effect was reproduced after balloon dilation of the small and large bowel.

It is clear that high pressure associated with use of large-size balloons and prolonged duration of the dilation increases the risk of perforation due to excessive damage of the esophagus. Progressive ischemic necrosis of esophageal mucosa could explain the so-called delayed perforation and false negative results of postprocedure chest and abdominal films and an esophagram with water-soluble contrast.

The procedure combines two different modalities: upper GI endoscopy and fluoroscopy. The child should be well prepared before dilation to decrease the risk of aspiration with residual food in the dilated and poorly emptying esophagus.

An endoscopy is an excellent tool for diagnosis of different causes of dysphasia such as complicated erosive esophagitis or Schatzki's ring. However, it does not play any role in the diagnosis of achalasia. An endoscopist can feel increased resistance while advancing a scope into the stomach, but it is quite subjective and can only raise suspicion about achalasia. Some bulging of the cardia can be seen during retroflexion occasionally. Stretching of the esophagus produces a different degree of quite intensive chest pain. That is why pneumatic dilation requires deep sedation or general anesthesia without muscle relaxant.

After the esophagus is explored, the shaft is advanced into the middle body of the stomach. A special guidewire (Microvasive, Boston Scientific Corp, Boston, MA) is inserted into the biopsy channel and positioned in the stomach at the level of angularis. An "exchanged" procedure is performed next: a guidewire is pushed slowly forward while the shaft is pulled back synchronously. After the endoscope is withdrawn completely, the position of a guidewire is verified under fluoroscopy. Then a guidewire is threaded inside Rigiflex dilator (Microvasive) and grabbed at the proximal site of the dilator. A well-lubricated dilator is slid to the mouth and slowly advanced into the esophagus under fluoroscopy.

A radiopaque double-line sign marks the middle portion of the dilator. It helps with proper positioning of the middle part of a dilator across the diaphragm. Then the balloon is inflated

under controlled pressure between 6 and 12 psi for a maximum of 1 minute. Special care should be taken to protect inflated balloon from slipping into the stomach. It is achieved by fluoroscopic control and appropriate backward tension of the dilator during inflation. According to our experience, a 30-second single dilation is optimal for children younger than 12 years. For teenagers we use a double-balloon technique with a 30-mm dilator for first 30 seconds, followed by the use of a 35-mm dilator balloon for an additional 15 seconds.

In our practice, this technique gives a better outcome for excellent or good results.

A careful observation for at least 4 hours and postprocedure chest x-ray are mandatory. Significant chest pain lasting more than an hour is a red flag for complication and initiation of treatment even without a proven pneumomediastinum or radiographic signs of perforation. Conservative management of perforation with broad-spectrum antibiotics, proton pump inhibitors, nothing by mouth and parenteral nutrition is very effective and carries less risk of morbidity associated with early surgery.

FOREIGN BODIES

Children with foreign bodies in upper GI tract require urgent care or cautious observation. Indications for urgent care are:

- Esophageal foreign body
- Sharp foreign body in the esophagus, stomach, and duodenum

Coins

Crawling infants and toddlers are the most common patients registered in emergency, with coin and other small objects in the cervical esophagus (Figs. 6.2 and 6.3). They could be symptomatic (e.g., gagging, drooling, coughing, wheezing, and breathing with stridor) or symptoms free. All symptomatic patients require urgent endoscopic intervention.

Few strategies are recommended for asymptomatic children with coins in the cervical esophagus:

- 12-hour observation
- Foley catheter removal technique
- Pushing a coin into the thoracic esophagus
- Delayed endoscopic procedure

In our opinion, these approaches are problematic. First of all, an accurate estimation of the time of ingestion is not always possible. Second, spontaneous migration of a coin into the stomach is quite unlikely with time, especially in infants. Third, significant

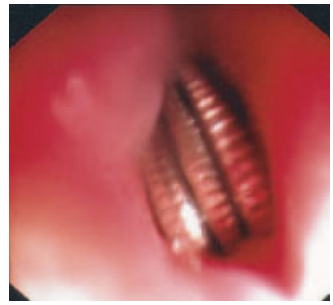


Fig. 6.2 Three coins (quarters) in the cervical esophagus. Two-year old girl was symptoms free at the time of endoscopic coins removal.

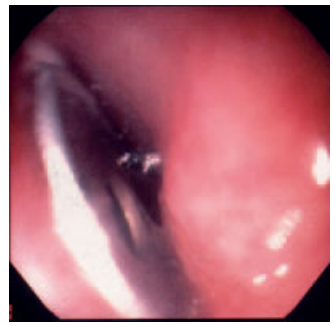


Fig. 6.3 The locker key is in the cervical esophagus. The toddler swallowed the foreign body 4 hours before he was brought in the emergency room. The child was symptoms free.

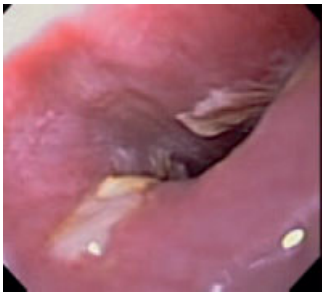


Fig. 6.4 Pressure necrosis of the cervical esophagus. It consists of symmetrical lineal lesions on the lateral walls of the cervical esophagus.

pressure necrosis of the cervical esophagus (Fig. 6.4) can occur as early as 4–6 hours after coin ingestion (personal observation). This complication requires hospitalization and treatment with nasogastric feeding and antibiotics for 5 days. Lastly, Foley catheter technique carries a small, but life-threatening, risk of a coin dislodgement into the larynx and asphyxia.

We manage all asymptomatic children with a coin in the cervical esophagus according the following algorithm (Fig. 6.5).

Endoscopic removal of a coin from the cervical esophagus can be done under deep sedation or general anesthesia with muscle relaxation. In our opinion, general anesthesia provides the safety and optimal condition for endoscopic removal of a foreign body.

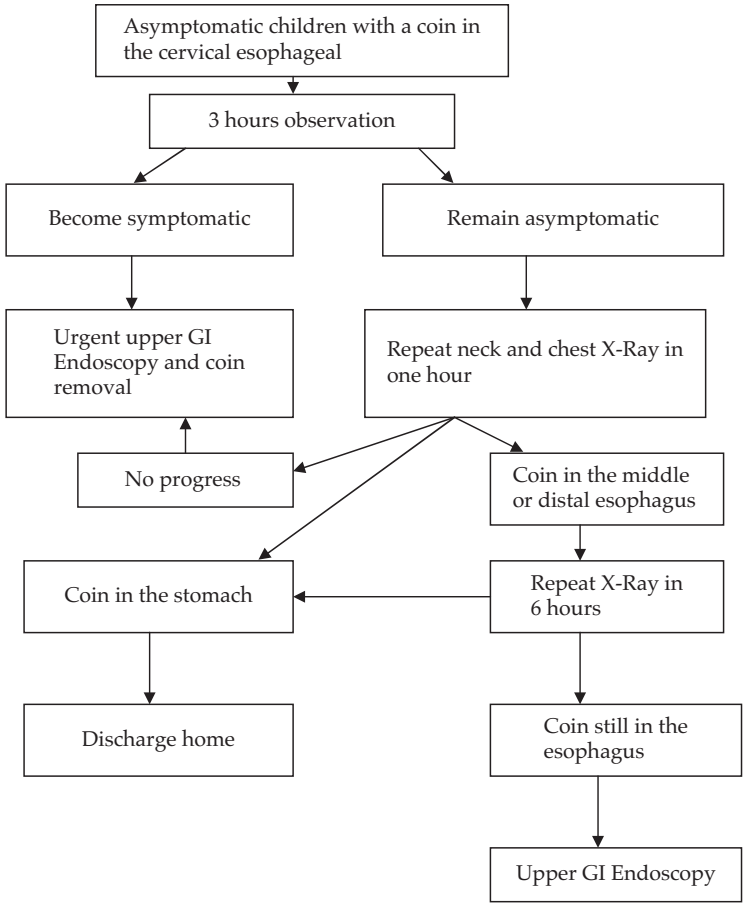


Fig. 6.5 Asymptomatic children with coin in the cervical esophagus: treatment algorithm.

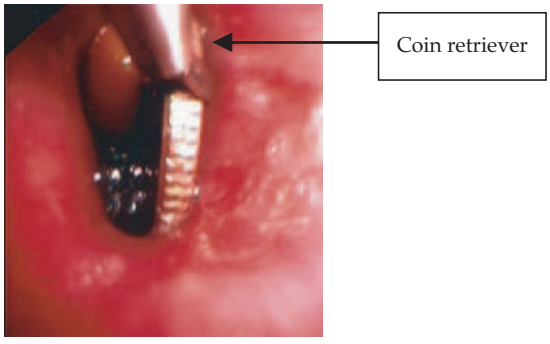


Fig. 6.6 Removal of the coin using a coin retriever device. The key is a proper placement of the retriever in the middle of the coin edge.

Technique of coin removal

The esophagus is intubated in a standard fashion (see Chapter 5). A coin is identified almost immediately if it is still there (occasional dislodgement can occur during endotracheal intubation).

The main challenge during the retrieval is high pressure produced by upper esophageal sphincter around a coin. Many devices have been used to remove a coin from the cervical esophagus: regular biopsy forceps, "alligators," a snare with a net, etc. According to our experience the foreign body retriever (Olympus Ltd.) is the only device that can grasp a coin between "teeth" and hold it tight enough to overcome the resistance of upper esophageal sphincter. An elevated edge of a coin prevents a retriever to slip away. The key to success is a proper position of the retriever right in the middle of a coin (Fig. 6.6).

Delicate manipulations with a shaft or control knobs help to bring the retriever in a plane perpendicular to a coin. Slight opening of the retriever can check it easily. The tip of a scope should be kept at about 1 cm from the edge of a coin to create enough space for safe manipulation.

The low branch of the device is sliding between posterior wall of the cervical esophagus and a coin almost blindly. However, a sharp tooth at the end of this branch is facing a coin. To eliminate any risk of mucosal laceration, careful positioning of the retriever is mandatory before an attempt to close it around the edge of a coin.

If opened branches are not strictly perpendicular to a coin and are off-center, a coin will most likely escape from the device. Once a coin is grasped and secured, keep a retriever tight and pull it back to bring the coin right to the tip.

Coil a retriever around the left index finger to secure the position of the coin. Release both control knobs and pull the shaft

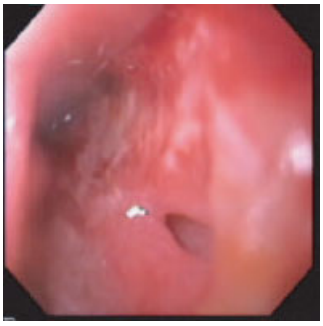


Fig. 6.7 Tracheoesophageal fistula. This complication has occurred in 2-year-old toddler, who swallowed 20-mm disc battery approximately 12 hours before it was removed.

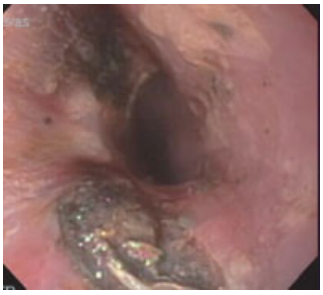


Fig. 6.8 A disc battery in the cervical esophagus.

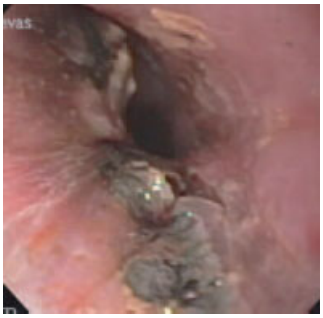


Fig. 6.9 View of the cervical esophagus after the battery was removed 5 hours after ingestion. Severe tissue necrosis has already occurred.

back. Apply some clock- or counterclockwise torque to facilitate sliding of a coin away from the cervical esophagus. Keep pulling back until a coin is removed successfully. If it is lost, remove a bite-guard and inspect the mouth by right index finger. If the coin is not found, repeat esophageal intubation.

Disc battery

A retained disk battery in the esophagus is a true medical emergency. Serious life-threatening complications including tracheoesophageal and aortoesophageal fistula and neck abscess can occur (Fig. 6.7). A disk battery creates a deep tissue necrosis in few hours (Figs. 6.8 and 6.9). A tremendous spasm of the crycopharyngeal muscle makes the situation even worse. A disc battery has a smooth edge. It further complicates the withdrawal process due to lack of appropriate grasping devices. Careful washing and aspiration of necrotic debris helps to find a battery and assess the damage.

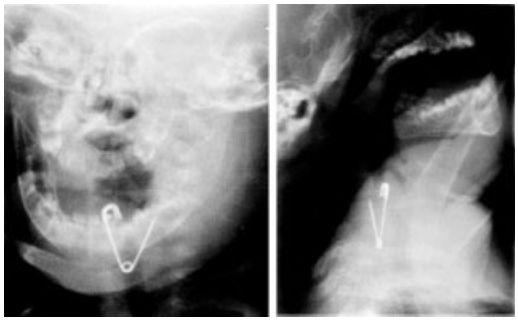
Attempts to push a battery into thoracic esophagus are never successful. Multiple trials usually failed before successful grasping and removal of a coin battery with retriever.

Rigid esophagoscopy is an option if a well-trained specialist is available.

V-shaped and other sharp objects

Any V-shaped object in the esophagus, such as an open safety pin with the sharp edge pointed cephalad (Fig. 6.10) has to be gently brought into the stomach, reversed, and removed in a retrograde fashion.

Any ingested sharp objects should be urgently removed from the stomach or duodenum (Fig. 6.11).



(a) (b)

Fig. 6.10 Open safety pin in the cervical esophagus. It was transferred into the stomach, reversed, and then safely removed using rat tooth grasper and protective rubber hood device.

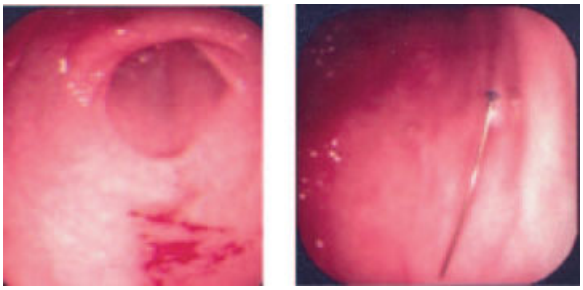


Fig. 6.11 A pin in the duodenum. A 15-year-old girl swallowed a pin accidentally. She was followed in the outside emergency room for 2 days. A battery of flat films showed a retained pin in the duodenum. Superficial mucosal trauma was found in the antrum. A pin was discovered and removed from the duodenum uneventfully.

Improvised protective device (e.g., a cylinder from the variceal bending set or plastic tube) can be attached to the tip. A grasped sharp object is pulled into the protective shield and removed with the endoscope.

ENDOSCOPIC HEMOSTASIS

Three main types of pathologies in pediatrics result in acute, moderate to severe gastrointestinal (GI) bleeding to warrant an urgent diagnostic and therapeutic upper GI endoscopy:

- Portal hypertension
- Acid peptic disease
- Vascular malformations

According to the technique employed, an endoscopic therapy of GI hemorrhage can be classified into three major categories:

- Nonthermal coagulation
- Constrictive, mechanical devices
- Thermal coagulation

A "Nonthermal" category comprises injection of hemostatic agent directly into the vessel or the surrounding tissue. Three types of substances are currently available: sclerosing agents, vasoconstricting agents, and polymeric "glue," e.g., histoacryl or cyanoacrylate.

Sclerotherapy

Endoscopic injection sclerotherapy (ES) is a highly effective alternative to the shunting procedure in patients with portal hypertension. It has increasingly been used in pediatric patients for rapid hemostasis and to reduce frequency of recurrent bleeding.

Elevated pressure in the portal system of either extra- or intrahepatic origin may appear as dilated esophageal and gastric submucosal veins (Figs. 6.12 and 6.13), hypertensive gastropathy

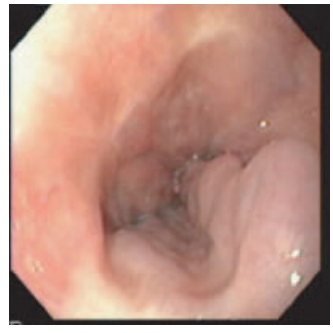


Fig. 6.12 Portal hypertension. Dilated esophageal veins in the distal esophagus.

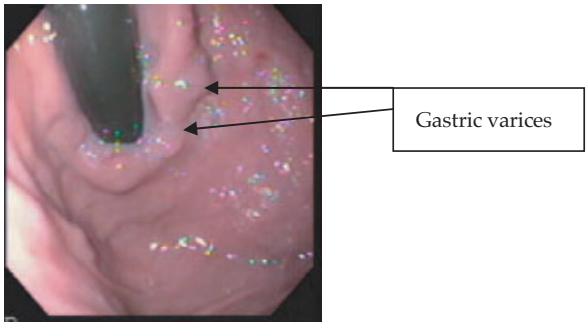


Fig. 6.13 Portal hypertension. Gastric varices are seen in the cardia.

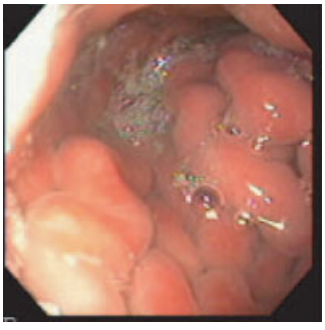


Fig. 6.14 Portal hypertension. Hypertensive gastropathy: edematous gastric folds with focal discolorations secondary to venous congestion.

(Fig. 6.14), and less often with plethoric veins or varices of the small and large intestine.

The indications for sclerotherapy are as follows:

- Active bleeding from esophageal varices
- History of upper GI bleeding
- A failed shunting procedure
- Prophylactic sclerotherapy is controversial.

The goal of sclerotherapy varies from temporary hemostasis in children waiting for liver transplantation to complete obliteration of varices in children with an extrahepatic block of portal flow.

The patient has to be stabilized hemodynamically before the procedure. The pressure in the portal system may be lowered by the administration of either vasopressin or somatostatin or its synthetic analog, octreotide (the latter two substances have less systemic side effects). Placement of a large-size orogastric tube is necessary for gastric lavage and assessment of bleeding activity in these cases.

Sclerotherapy can be performed during acute variceal bleeding, but it is a challenging procedure with high risk of complications.

If the intensity of hematemesis excludes urgent endoscopy, the Sengstaken-Blakemore tube is indicated. After initial fluid resuscitation and stabilization, the patient has to be appropriately sedated. General anesthesia with endotracheal intubation is the method of choice for children with moderate to severe bleeding. It decreases the risk of aspiration and prevents agitation of the child during injection. Intravenous sedation could be an option for follow-up sessions. Prophylactic antibiotics are a routine part of our protocol. Prior to sclerotherapy, panendoscopy is required to rule out the coexistent sources of bleeding.

Many different sclerosants, including ethanol, sodium morrhuate, ethanolamine, and tetradecyl have been used. In general, lipid-soluble sclerosants have more systemic side effects

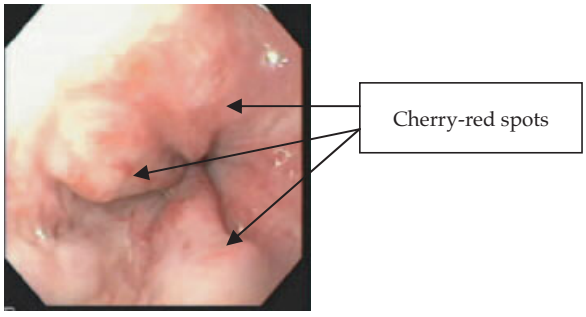


Fig. 6.15 Cherry-red spot. The varices with this mark care the high risk of bleeding.

(fever, pleural effusion, chest pain, or acute respiratory distress syndrome). The incidence of complications is directly related to the total amount of sclerosant utilized.

Injection of sclerosants can be done either intra- or paravariceally (or both) through a 25- or 27-gauge needle starting from the Z-line and moving cephalad in a spiral fashion along the lowest 5 cm of the distal esophagus. If there is no sign of active bleeding, tortuous varices with cherry-red spots, red wale markings, or hematocytic spots have to be sclerosed first, as they have a higher risk of rupture (Fig. 6.15). In our practice we use an intravariceal injection of 0.5–1.0 ml of diluted ethanolamine per spot, and not more than 5–6 ml per session. "Bleaching" varix is a marker of adequate amount of sclerosing agent. Injection of a sclerosant while retrieving a needle may protect from oozing blood from the site of injection. Simple advancement of the endoscope into the stomach creates sufficient pressure for hemostasis if oozing has occurred. Decompression of the stomach after each injection is necessary to prevent aspiration.

After initial endoscopic hemostasis (which is successful in more than 80% of cases), repeat sessions of sclerotherapy are necessary for complete obliteration of varices. Usually it is performed once a week in the first month, followed by a monthly schedule as indicated. In case of deep esophageal ulcers, the scheduled session of sclerotherapy has to be postponed. The incidence of recurrent variceal bleeding fluctuates between 8 and 31%. The bleeding may be severe but usually is controlled endoscopically. A majority of uncontrolled bleeding is related to gastric varices or severe hypertensive gastropathy.

An average of 4–6 sessions of sclerotherapy are necessary for complete obliteration of esophageal varices. Several complications of sclerotherapy have been described. The most common one is transient chest pain and low-grade fever, followed by esophageal ulceration (3–33%), bleeding from the site of injection, and esophageal stricture (4.5–20%).

As a rule, the small shallow esophageal ulcers do not have any medical significance and heal spontaneously or with the treatment of sucralfate, H2 blockers, or proton pump inhibitors. Deep ulcers may be the source of bleeding or esophageal stricture and have to be treated aggressively. An esophageal stricture due to sclerotherapy is easily managed by dilatation. Transient changes of esophageal motility and gastroesophageal reflux (GER) have been described in adults but the real incidence of these complications in children is unknown.

Epinephrine injection therapy

Epinephrine in saline (1:10,000) is the most commonly used vasoconstrictive agent for hemostasis in children. It is delivered to the source of bleeding through the same 25–27-gauge sclerotherapy needle. The needle should be completely filled in with epinephrine before insertion into the biopsy channel to prevent air embolism during injection. This type of hemostasis can be used alone or in combination with thermal or mechanical devices. Indications are as follows:

- Bleeding peptic ulcer
- Bleeding arteriovenous malformation
- Bleeding during and after polypectomy

Epinephrine is injected in 0.5–1.0 ml aliquots around the bleeding site. In our practice, a total volume of epinephrine rarely exceeds 4 ml per bleeding site. Injection of epinephrine can induce white discoloration of the tissue around a needle, secondary to vasoconstriction.

Constructive, mechanical devices

Endoscopic variceal ligation

Endoscopic variceal ligation (EVL) has been successfully used in adults for more than a decade. The technique of EVL is relatively simple and can be very effective for hemostasis of bleeding varices.

Available data support at least an equal efficacy of EVL and ES in terms of eradication of varices and/or frequency of rebleeding. Moreover, recent publications challenged a concept of ES as the treatment of choice of esophageal varices. EVL decreases the number of endoscopic sessions necessary to eradicate esophageal varices. It also reduces the frequency of local complications such as deep ulcerations and strictures.

Several factors have been slowing the use of EVL in pediatrics. The major one is the size of the ligation device. It is designed for an endoscope at least 10 mm in diameter. According to our experience and published data, EVL can be safely performed in children over 4 years of age. The device consists of two cylinders. The

outer cylinder is mounted on the top of an endoscope. The inner cylinder has "O" rings (up to 10 rings in the last models), which can be released by a trigger unit attached to the biopsy channel and connected to the inner cylinder through the trip wire.

A diagnostic upper GI endoscopy has to be performed immediately prior to mounting the ligation device to verify the source of recent bleeding and help to design the plan of action (bending schedule). The precise strangulation of the first varix is important for several reasons:

1 A maximal decrease in blood flow can be achieved if the esophageal view was occluded just above the Z-line.

2 A strangulated varix can narrow the esophageal lumen, especially in very young patients, making detail observation of the esophagus more difficult.

3 An attempt to advance an endoscope beyond the ligated varix can dislodge the O ring.

The varix has to be suctioned into the inner cylinder. Then the varix is strangulated by the O ring released from the inner cylinder by the trip wire (Fig. 6.16).

Three to six bands are applied in an upward spiral fashion every 1–2 cm. It is reasonable to limit the number of bands to 3 or less per session in the smallest patients to avoid esophageal obstruction with secondary dysphagia.

Repeat EVL is necessary within 3–4 weeks and then continuously on a monthly basis until complete eradication of the varices is achieved. The most common complication of EVL is esophageal ulceration. Unlike ulcers after ES, EVL-induced ulcers are usually more superficial. Transient chest pain, odynophagia, and dysphagia have been reported.

Long-term efficacy of EVL to prevent rebleeding after variceal eradication in children is unknown. Preliminary results of short-term follow-up data are compatible with the outcome of ES. However, long-term follow-up studies are necessary. An absence of systemic complications along with further modifications of the ligator device suitable for the smaller pediatric endoscopes could make EVL a treatment of choice for variceal bleeding in children.

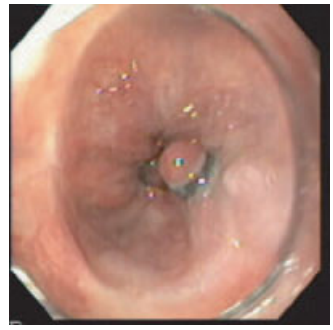


Fig. 6.16 Portal hypertension. Appearance of the varices in the distal esophagus after the bending procedure was performed.

Metal clips

Current metal clip technology is far from ideal due to following reasons:

1 Quite complicated preparation of the device before insertion into the biopsy channel

2 Frequent unintentional deployment of the clip before proper mounting on a site of bleeding

3 High cost

However, the procedure itself is relatively easy and could be very effective. Few clips are usually necessary to achieve hemostasis.

Indications for metal clip hemostasis are as follows:
- A visible bleeding vessel
- Dieulafoy lesions

Recently, few cases of endoscopic treatment of perforation with clip device have been described.

Thermal coagulation

Thermal hemostasis embraces different methods, which induce coagulation of a bleeding lesion. Some of these techniques, such as mono- and bipolar probes, have been invented into pediatric practice since late eighties and early nineties, respectively. New devices, e.g., heater probe and laser coagulation, became slowly available to pediatric gastroenterologists primarily in the medical centers, with coexisting adult and pediatric endoscopy teams. The cooperation is advantageous for both groups sharing equipment and expertise.

It also gives an opportunity for pediatric gastroenterologists to be exposed and to accumulate experience in advanced endoscopic hemostasis. However, it is a slow process due to limited number of children with nonvariceal GI bleeding. It will be fair to say that even in large centers of adult gastroenterology, only a small number of members make what has been known as the "hemostatic" team. A limited volume of pediatric patients with acute GI bleeding complicates a validation of efficacy and outcome of advanced hemostatic techniques in pediatrics. Perhaps, multicenter or even multinational studies are the answer to the problem.

Methods of thermal coagulation

There are five types of thermal technologies available for endoscopic hemostasis:
- Monopolar
- Bipolar/multipolar
- Heater probe
- Laser[1]
- Argon plasma coagulation (APC)

Indications for endoscopic hemostasis with thermal probes

1 Arterial bleeding:
   - Ulcer with bleeding or nonbleeding visible vessels
   - Mallory–Weiss tear with active bleeding
   - Dieulafoy's lesions

[1] Laser hemostasis is not discussed in this chapter due to lack of personal experience.

2 Nonarterial bleeding:
- Oozing of blood from ulcer or Mallory–Weiss tear with stigmata of hemorrhage (visible vessel or adherent clot)

3 Bleeding angiomata (arteriovenous malformation)
4 Bleeding during and after polypectomy

Monopolar devices

A monopolar system produces coagulation of the tissue in contact with the probe by thermal effect of electric current between the active internal electrode inserted into the biopsy channel and indifferent electrode mounted on the patient's skin. The generated energy is capable to produce coagulation in a deep tissue (up to 5 mm) adjacent to the active electrode. Undesirable effects of monopolar techniques are:
- Unpredictable depth of tissue damage and efficacy of hemostasis
- Excessive sticking of coagulated tissue to the active electrode
- High risk of rebleeding with an attempt to pull the probe away from the bleeding spot
- Ineffective hemostasis with tangential position of the probe to the surface of a bleeding lesion.

Currently, it is rarely used in pediatrics.

Bipolar/multipolar devices

Incorporation of the second active electrodes into the probes of bipolar or multipolar (two pairs of active electrodes) thermal coagulation devices illuminates the need for an indifferent electrode. Advantages of the system are:
- Large area of contact minimizes tissue sticking to the probe and risk of rebleeding
- Lesser deepness of thermal coagulation
- Effective coagulation with tangential position of the probe, which is essential for hemostasis of duodenal ulcers
- Automatic control of energy
- Incorporation of water irrigation system inside the probe

Computer-controlled thermal probes (heater probes)

The device generates and controls heat up to 250°C by pulses of energy delivered to silicone clip surrounded by a low-heat-capacity metal envelope without any electric current in the tissue. The probe is supplemented by a three-water jets system.

The metal envelope warms up to designed temperature in less than 0.2 seconds and cools off in less than 0.5 seconds. The computer controls the temperature and total energy delivered to the tissue. The endoscopist programs the computer to deliver

a specific amount of energy from 5 to 30 J tailored to specific bleeding source.

Bipolar/multipolar and heater probes have been used more often in pediatric patients than any other type of thermal hemostatic devices. Commercially available probes fit easily into the 2.8-mm biopsy channel of pediatric endoscope. Both methods provide enough heat for coagulation of mesenteric arteries, up to 2 mm, in experimental models. Advantages of the heater probe include: no direct contact of electricity with the tissue, adjustable depth of coagulation, and no adherence to the tissue.

Argon plasma coagulation

Plasma coagulation is the result of ionization of a noble gas (argon is the cheapest one), which fills a small gap between the electric electrode and the target tissue. Ionization of argon occurs when a high-frequency current creates sufficient electric field strength.

Ionized argon conducts an electric current and flows along the same pathway. Plasma beams are generated when the strength of the electric field reaches a critical point of 500 V/mm.

The released energy induces desiccation and coagulation without carbonization and evaporation, which prevent deep tissue destruction. Electrically active beams travel from the electric electrode to the closest electrically conductive tissue, regardless whether it is in front or lateral to the electrode. Loss of tissue conductivity due to desiccation switches the direction of electric and plasma flow toward the adjacent nondesiccated area with normal electric conductivity. The process persists until the electric current cannot reach the tissue with normal electric conductivity. The depth of coagulation is proportional to the power setting and application time but almost never exceeds 4 mm. Holding a probe in one site for 5 seconds produces coagulation of 2–3 mm deep with the power setting of 30–60 W.

The advantages of APC coagulation are larger area of coagulation compared with contact types of mono- and bipolar coagulation methods and decreased depth of tissue destruction. The disadvantages are related to absolute necessity to keep the probe of the tissue at an optimal distance for coagulation and also accumulation of argon in the stomach or intestine, which could lead to stretching and thinning of the wall. A direct contact of the probe with mucosa is dangerous due to risk of transmural tissue damage and perforation. On the contrary, argon plasma sparks will not occur if the distance between the probe and tissue is too long. Instead, air plasma may be induced with rather theoretical risk of carbonization, evaporation, and deep tissue destruction because it travels over an extremely short distance.

The technical aspects of APC are quite simple. Few sessions are usually enough to create a skill for an optimal and safe placement

of the probe above the target lesion. Air insufflations should be minimized even more than during routine procedure. Thin (1, 5 mm) probes are commercially available and suitable for small caliber pediatric endoscopes. This makes passable to apply APC even in neonates and infants.

Three types of complications have been described in adults: perforation or submucosal emphysema due to direct contact of the probe with mucosa and flow of argon gas through the damaged mucosa and colonic distention. Future studies are necessary for validation of APC in children.

Technique

Detail description of edoscopic hemostasis with different devices is beyond the scope of the chapter.

Before the procedure, a pediatric gastroenterologist should become familiar with the available equipment, types of produced energy and tissue responses to generated heat, proper setting of the coagulator, and optimal treatment requirements for different types of bleeding lesions.

The main rule of any thermal hemostasis is escalation of tissue damage with higher pressure applied to the bleeding lesion, increased power output of generator, and duration of the treatment. There is no validated parameter in children for different types of bleeding lesions and different probes.

Further studies are required for optional thermal endoscopic hemostasis in pediatric patients.

PERCUTANEOUS ENDOSCOPIC GASTROSTOMY

Introduction

The first percutaneous endoscopic gastrostomy (PEG) tube placement was reported in 1980 by Ponsky, Gauderer, and Izant. PEG tube insertion was initially reported in pediatric patients, was subsequently popularized in adults, and was later reintroduced for use in children by pediatric gastroenterologists. Although initially developed by surgeons, it is now performed at an equal or greater frequency by adult and pediatric gastroenterologists. Despite many similarities in the indications and some technical aspects of the procedure between children and adults, there are also significant differences in the indications, limitations, and technical aspects of the procedure.

Indications

PEG tubes are appropriate in any pediatric patient who requires a gastrostomy tube and does not require a simultaneous open

abdominal procedure. PEGs can be placed for medication administration, feeding administration, gastric decompression, or a combination of these reasons. Patients undergoing a simultaneous fundoplication, pyloroplasty, or pyloromyotomy would likely not derive additional benefit from placement of a PEG tube versus a surgical gastrostomy. PEG tube placement does not interfere with subsequent fundoplication, pyloroplasty, or pyloromyotomy.

Benefits of PEG tube insertion compared to a surgical gastrostomy include reduced procedure time and cost, smaller incision, shorter length of stay, decreased incidence of postoperative GER, and a decreased incidence of postoperative complications including wound infection, wound dehiscence, bowel obstruction, pain, atelectasis, and impaired mobility.

Contraindications

There are only a few absolute contraindications to PEG placement. PEG tubes should not be attempted if there are patient factors that interfere with successful transillumination of the gastric wall or with identification of the indentation performed during the procedure or if there is a suspicion that the anterior gastric wall is not opposed to the abdominal wall such as in the case of an intervening colon or other abdominal organ. If the anterior gastric wall cannot be opposed to the anterior abdominal wall due to ascites or similar conditions, PEG placement may not be feasible. As with any endoscopic procedure, the patient should be medically stable, airway protection and management is imperative, and the endoscopist should be willing to abort the procedure if the procedure is not progressing as anticipated.

PEG tubes may be more difficult to place or may not be able to be placed, should be placed with increased caution, may require additional preprocedure evaluation and extra care in patients with the following conditions: ascites or those on peritoneal dialysis; scoliosis or spine abnormalities; small size, ventriculoperitoneal shunts; prior abdominal surgery; congenital abnormalities such as situs inversus, hepatomegaly, splenomegaly, or other abdominal masses; small laryngeal or tracheal size, tracheal compromise, or ventilatory issues. The presence of gastric ulceration or gastric varices may preclude PEG placement.

Decision to proceed with PEG

The preprocedure evaluation in most centers has evolved with time, may vary with indication, and varies between centers; for example, in a well-nourished neurologically impaired child who is having a PEG tube placed for medication administration only, a preoperative evaluation for reflux may not be indicated. In the

same child who has severe vomiting and failure to thrive, additional testing including 24–48-hour pH probe testing may be indicated preoperatively to determine if a simultaneous antireflux procedure is indicated. Open gastrostomy is associated with a significantly increased risk of severe postoperative GER compared to PEG insertion (odds ratio 6–7:1). Potential contributing factors include alteration of the angle of His and reduced LES pressure by an open gastrostomy. In our center, the standard evaluation prior to PEG insertion includes an upper GI x-ray to exclude malrotation and to identify if part of the stomach is located below the rib cage. In patients who are having PEGs placed for feeding, we prefer, if medically possible, to do a trial of outpatient nasogastric (NG) feedings for approximately 10 days prior to placement of the PEG tube. The patients who are intolerant of NG feeds can undergo additional evaluation for an antireflux procedure. The patients who tolerate the feedings, generally gain weight and improve their nutritional status prior to the operative procedure. Three important considerations are (i) PEG tubes do not prevent aspiration in a patient with oral pharyngeal dysphagia who continues oral feedings, (ii) if the stomach is completely under the rib cage, a PEG is unlikely to be successfully placed, and (iii) like NG tubes, PEG tubes can be pulled out.

Patient preparation

The patients should be NPO (nil per os) prior to the procedure. Administration of preoperative antibiotics with good coverage for skin flora and two additional peri/postoperative doses has been shown to decrease the incidence of postoperative wound infections. The abdomen should be prepped and draped as for a standard operative procedure. Because of the lack of anticipated patient cooperation in pediatric patients, the type of pull technique that we utilize, and the need for airway protection, we generally perform this procedure utilizing a general anesthetic or sedation provided by a pediatric intensivist, although some centers utilize conscious or "deep" sedation. Deep sedation has been reported to be successful even in children with underlying congenital heart disease.

Technique

Personnel: in most pediatric centers, two physicians perform PEGs; one performs the endoscopic portion of the procedure and the other the abdominal portion of the procedure including catheter insertion. In our center two pediatric gastroenterologists do this. In some centers the procedure may be performed in conjunction with a pediatric surgeon or with an interventional radiologist. Insertion of a PEG tube is an advanced endoscopic

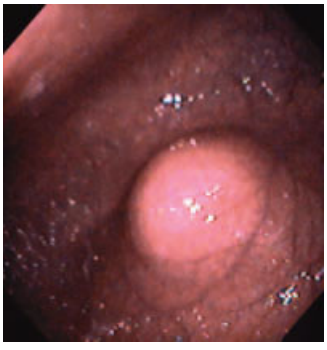


Fig. 6.17 Finger indentation of the anterior gastric wall prior to trocar.

procedure, with a higher rate of associated complications, and the performing physicians must be able to recognize if the procedure is proceeding in a nonstandard fashion and be able to make rapid adjustments or terminate the procedure if necessary.

Working as a team, the endoscopist will pass the appropriate-sized endoscope to fill the greater curvature of the stomach without intubating the pylorus. Excessive air insufflation (insufflation that significantly flattens the gastric rugae or results in visible abdominal distension) should be avoided as this may distend the small bowel loops and interfere with the gastric indentation. The other physician who is "sterile" throughout the procedure will then perform finger indentation to identify an impression along the anterior gastric wall, preferably away from the gastric cardia and located near the junction of the gastric body and the antrum. (Fig. 6.17) The indentation should be perpendicular to the anterior gastric wall to avoid entering the stomach inferiorly, which may increase the risk of entering the colon or its mesentery. The indentation should also be away from the costal margin as tubes placed too close to the ribs can be associated with significant pain.

After identification of a good impression, the sterile physician will inset a 25- or 21-G needle attached to a syringe usually filled with 1% lidocaine solution to test the tract identified by the gastric indentation. This needle should pass into the stomach under the direct vision of the endoscopist to the same length as the anticipated internal length of the PEG tube. Failure to see the passage of the needle into the stomach when it is inserted to its hub suggests that repositioning of the PEG site is necessary or that there is an intervening organ such as colon or bowel mesentery. One percent lidocaine is injected with needle withdrawal. Some endoscopists will watch for bubbling of air in the syringe of the needle with insertion. This is known as the "safe tract" technique (Fig. 6.18). Visualized air bubbling prior to the endoscopist seeing the needle in the stomach may indicate an intervening loop of bowel, which can result in complications as described below.

After a good site is identified, the sterile physician will make a small incision in the anterior abdominal wall at the site of catheter insertion. This is usually transverse and should be through the skin and large enough to allow passage of the PEG tube, but not large enough to require suturing. On occasion this incision will need to be extended during the pull aspect of the PEG if not initially large enough to allow the catheter to be pulled through the anterior abdominal wall. Too small an incision and therefore too tight a catheter increase the risk of postoperative wound infection and development of granulation tissue.

Under direct endoscopic vision the sterile physician will then repeat the angiocatheter insertion, using the same technique, although usually with a larger size (14-G) cannula/catheter that

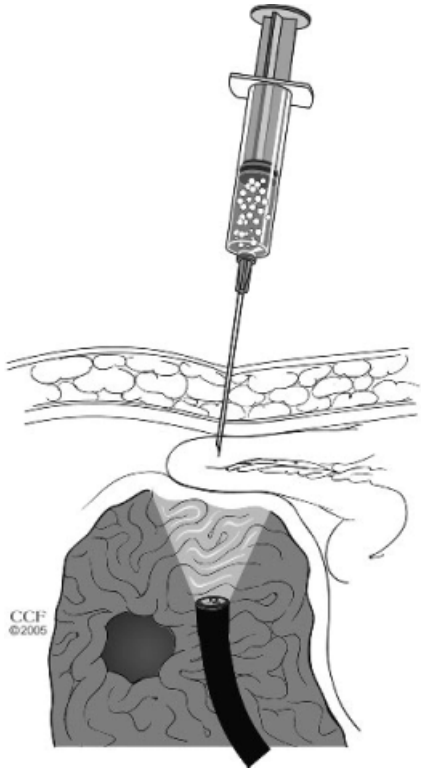


Fig. 6.18 Schematic representation of the safe tract technique. In this case, a loop of bowel is present between the anterior gastric wall and the anterior abdominal wall. On occasion, this can be identified during the procedure by noting air bubbles in the syringe, *without* the endoscopist seeing the cannula in the gastric lumen. The trocar should be removed and repositioned to an alternate site, or the procedure should be converted to an open gastrostomy.

will accommodate passage of the guidewire. As soon as the catheter is visualized in the stomach, the endoscopist passes biopsy forceps or a snare through the biopsy port in order to grasp the guidewire, which the sterile physician is simultaneously passing via the cannula through the anterior abdominal wall (Fig. 6.19). Preferential use of forceps versus a snare is at the discretion of the endoscopist. The sterile physician should hold the catheter carefully at all times until the endoscopist secures the guidewire. Once the guidewire is secured, the procedure can almost always be safely completed, but accidental dislodgement of the cannula prior to guidewire insertion can result in a free perforation or other complications. For smaller endoscopes with a 2-mm channel, guidewires are grasped utilizing small forceps. Small-sized alligator forceps have also recently become

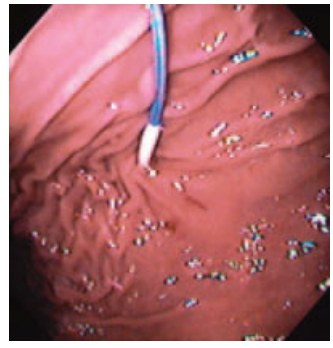


Fig. 6.19 Placement of the blue guidewire through the catheter. A sufficient length of guidewire should be passed through the catheter to grasp with the endoscopic forceps.

available. For standard endoscopes with a 2.8-mm channel, the guidewire can be grasped using standard forceps, foreign body forceps such as alligator or rat-tooth forceps, or a polypectomy snare. Some endoscopists elect to position an open snare around the expected entrance of the cannula into the stomach to facilitate grasping of the guidewire.

On occasion, a portion of the cannula is seen in the stomach, but not enough that the endoscopist feels comfortable with the length of the cannula in the stomach, or the cannula may be seen coming up through the lower esophageal sphincter into the esophagus in very small patients or across to the posterior gastric wall. The endoscopist can use very gentle endoscopic traction to reduce tenting of the gastric wall on the cannula, which will allow advancement of the cannula safely into the stomach without through-and-through placement. Additional air insufflation immediately prior to catheter puncture may also help if the gastric indentation is not optimal.

After the endoscopist grasps the guidewire, the guidewire and endoscope are withdrawn through the esophagus and out the mouth. After withdrawal, the endoscopist will attach the PEG catheter to the guidewire. If using a looped guidewire, it is optimally attached at the very tip of the loop. The endoscopist will then guide the well-lubricated catheter down the patient's mouth and into the esophagus while the sterile physician is pulling the catheter gently through the anterior abdominal wall. There may be some resistance when the guidewire catheter knot reaches the abdominal wall. In this case, slightly extending the incision may facilitate passage through the wall, and circular rotation of the guidewire with steady traction by the sterile physician will facilitate this maneuver. In the off chance that the guidewire breaks, as it is coming through the abdominal wall, hemostats can be used to bring the guidewire and catheter through the abdominal wall. Excessive traction should be avoided especially in small, malnourished, or immunocompromised patients, as there have been reports of catheters being pulled entirely through the abdominal wall.

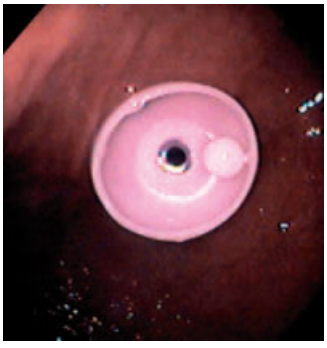


Fig. 6.20 Internal view of a PEG tube along the anterior gastric wall. The particular tube used has a nondeflatable internal disc, which acts as the internal bolster.

The endoscopist will verify the position of the PEG tube and the length to the skin (Fig. 6.20). If excessive length to the skin is present (i.e., 5–6 cm in a small child) the endoscopist should consider that something might be trapped between the stomach and the anterior abdominal wall. Most PEG tube lengths will be similar to standard gastrostomy button lengths, which pediatric gastroenterologists are used to estimating.

An external bumper secures the PEG, leaving room for swelling in the immediate perioperative period. The incision is dressed with an antibiotic ointment, and additional intravenous antibiotics are administered in the postoperative period usually for two additional doses. The tubes can generally be used within 6–24 hours. Early initiation of post-PEG feedings is not associated

with an increased complication rate but may be associated with higher gastric residual volumes. We typically initiate feedings with a clear liquid, such as a balanced electrolyte solution, prior to initiation of formula feedings. Feedings are advanced based on the individual patient's tolerance.

Consideration should be given to aborting the procedure if any of the following are identified or occur: failure to identify a good gastric impression, excess angiocatheter length without seeing the tip in the stomach, air bubbling in the needle syringe without seeing the tip in the stomach, gastric varices or significant ulceration, and identification of fecal matter at any point during the procedure.

Postprocedure management

We generally do not change catheters within 6 weeks of the procedure and preferably wait at least 2 months after placement to allow for tract maturation, although percutaneous replacement of PEG tubes following accidental dislodgement has been reported within a couple of weeks of placement. Because traction removal of catheters may be uncomfortable for children and traumatic to the tract and because we use a catheter with an internal bumper equivalent, we prefer to change them under anesthesia. We re-endoscope the patient at the time of catheter change, and cut and retrieve the catheter. The internal aspect of the catheter once cut is usually retrieved using alligator forceps or a small snare. Removal with the long axis of the cut PEG tube parallel to the axis of the esophagus rather than perpendicular is preferred, especially in smaller patients or with larger PEG tubes. Cutting the PEG tube as close to the skin as possible, thereby leaving a shorter internal portion to be retrieved, facilitates removal. We do not cut the bumper and allow it to pass, as intestinal obstruction, impaction, and perforation have been reported with cut and unretrieved bumpers. We also endoscopically visualize placement of the new gastrostomy button at the time of initial conversion from a PEG tube. If the button is placed in the tract but is not visualized in the stomach, there may be a false tract or a portion of the colon or small bowel may have been trapped between the PEG tube and the abdominal wall, and the "g-tube" button may be located in the colon, small bowel, or mesentery. Surgical consultation is appropriate at this point.

Complications

Complications of PEG placement can be minor, major, early, or late. New and unusual complications continue to be reported. Their rates in the literature vary but are generally in the range of 5–30%. Some are preventable with appropriate antibiotic prophylaxis, good endoscopic/percutaneous technique,

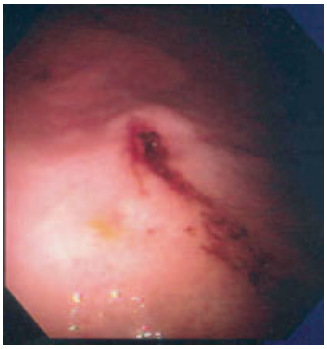


Fig. 6.21 Buried bumper syndrome. The bumper of the gastrostomy tube is no longer in the stomach. However, it remains in the abdominal wall close to the stomach. The shadow of the bumper is still visible.

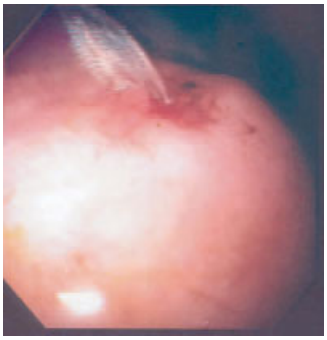


Fig. 6.22 The gastrostomy tube is buried in the abdominal wall, although the stoma remains open. This was confirmed by injection of small amount of saline.

and recognition by the physicians performing the procedure that things are not going well, with a decision to abort the procedure and precede with an open gastrostomy. Sometimes as with percutaneous liver biopsy, complications are unavoidable due to patient anatomy or underlying disease and the possibility of these complications should be discussed with parents prior to the endoscopic procedure. Reported minor complications that can become major complications include cellulitis, uncomplicated pneumoperitoneum, tube defects/disconnection, GER, granulation tissue at insertion site, and pain at the insertion site. Reported major complications include gastrocolic fistula, gastroileal fistula, gastrocoloileal cutaneous fistula, intrahepatic placement, duodenal hematoma, complicated pneumoperitoneum, aspiration, peritonitis, catheter complications including migration, buried bumper syndrome (Figs. 6.21–6.23), partial gastric separation, catheter/bumper impaction if not retrieved, intussusception secondary to catheter migration, VP shunt infection, gastric or bowel perforation, and death. Late complications include gastrocolic fistula, gastroileal fistula, catheter migration/buried bumper syndrome/partial gastric separation, gastric ulceration, cellulitis, fasciitis, gastric or bowel perforation, catheter migration or other catheter-related complications, bronchoesophageal fistula (following removal), and aortic perforation (following cut and pass technique). PEG tubes in children are not associated with a higher rate of subsequent revision when compared to surgically placed open gastrostomy tubes if tube revisions due to unrecognized bowel perforation at initial PEG placement are excluded.

New uses of the PEG technique

Innovative pediatric and adult gastroenterologists and surgeons have further modified the techniques of PEG. Utilizing modifications of the PEG technique, tubes can be placed directly

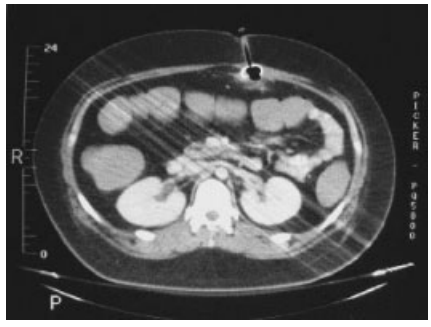


Fig. 6.23 The extramural type of buried bumper syndrome was confirmed by CT scan.

1 This is a procedure that is best done quickly. Once the endoscopic portion of the procedure starts, it is usually accomplished by an experienced team within approximately 10 minutes. Longer procedures are associated with excessive air insufflation, which makes identifying the gastric impression more difficult and may increase the risk of distending the small bowel or colon with air, and therefore interposing a loop of bowel between the stomach and the anterior gastric wall with its resultant complications.
2 If things are not going well in terms of positioning, the PEG tube should not be placed. There may be something – liver, bowel, mesentery, etc. – between the trocar and the anterior gastric wall. Unless the liver has been punctured, these complications are usually self-limited if the angiocatheter/trocar is removed and the PEG is not placed.
3 If significant bleeding occurs or stool is visualized at any point, surgical consultation is appropriate.
4 When faced with a patient with atypical anatomy (cardiac surgery patients, patients with a scoliosis, etc.,) the PEG may require placement in a nonstandard position (i.e., right side of the abdomen in a patient with situs inversus). The endoscopic technique should be similar to the standard procedure. Avoid location selection by formulas (i.e., one-third the distance between the xiphoid and the umbilicus). Pick the location that is best, based on the individual patient's anatomy.
5 The buried bumper syndrome. The gastrostomy bumper is no longer in the stomach. The complication did occur in teenagers who suffered form severe botulism toxicity. Muscle paralysis was a contributing factor to the rare complication.
6 The existing fistular was confirmed by injection of small amount of saline.
7 A CT scan showed extragastric location of the buried bumper.

Table 6.1 Tricks of the trade.

in the jejunum (PEJ) for feeding and in the cecum (PEC) for antegrade colonic enemas. The PEJ technique currently has limited applicability in young children due to equipment and size limitations. If larger series confirm earlier reported success with PECs, this is likely to become an increasingly reported technique in children with neurologic abnormalities and developmental abnormalities resulting in chronic constipation.

Conclusions

PEGs are being increasingly utilized in pediatric patients. Placement of a PEG tube does not increase the incidence of postoperative GER and does not interfere with subsequent gastric surgery. PEG placement is an advanced endoscopic procedure associated with a higher rate of complications than standard esophagogastroduodenoscopy. Placement of PEGs in children requires modification of the technique required in adults due to size and anatomic considerations and also due to different anticipated duration of use. The key points of the safe technique of the PEG placement are summarized in Table 6.1.

NASOJEJUNAL TUBE PLACEMENT

A nasoduodenal or a nasojejunal tube feeding is commonly used in children with severe GER as a bridge nutritional therapy before surgery or nutritional support for critically ill children with various conditions in intensive care units.

An enteral tube may be placed endoscopically if other options such as spontaneous passage or installation under fluoroscopy with the use of a radiopaque guidewire have failed.

After the appropriate tube is chosen, it should be prepared by placement of one silk suture at the tip. The patient is sedated and put in the left lateral decubitous position. The tube should be inserted into the stomach via the nose, first, followed by the endoscope. The tube may be found as either conveniently positioned along the greater curvature of the stomach pointing to the antrum or coiled in the gastric body. In the second scenario, it is pulled back until the tip is visible. The tube with an internal guidewire can be advanced forward if it is not coiled. A smooth surface of the antrum and lack of mucosal folds simplify grasping of the silk string. A regular biopsy forceps is preferable to use for grasping because it usually eliminates sticking of the suture to the grasper and accidental dislodgement of the tube from the duodenum or jejunum back to the stomach during withdrawal of the forceps. A significant friction between the scope and the feeding tube creates a passive engagement of the nasoduodenal or nasojejunal tube when the shaft is advanced toward pylorus. Therefore, the external part of the tube should be secured to prevent an excessive insertion and coiling of the tube in the stomach.

Once a regular forceps grasps the silk suture, it is dragged in the biopsy channel to align the feeding tube with the tip of a scope. The shaft of the endoscope is maneuvered through pylorus into the distal duodenum or proximal jejunum in a standard fashion. Then the forceps is pushed forward for a few centimeters while the shaft is pulled back for the same distance simultaneously. These "exchange" sequences are repeated until the tip of the scope is drawn back to the antrum. A view of the forceps and the tube engaging through the pylorus is reassuring that the exchange procedure was performed successfully. After that the biopsy forceps is opened to release the string attached to the tube and pulled back into the stomach and closed before complete removal. Finally, the shaft is pulled out using side-to-side gentle rolling technique to decrease friction and accidental dragging of a feeding tube back into the stomach. The position of the tube along the lesser curvature is ideal (Fig. 6.24).

Simple postprocedure flat abdominal film or fluoroscopy confirms the appropriate position of the feeding tube.

A similar technique can be used for placement of the gastroduodenal or gastrojejunal feeding tube in children with an established gastrostomy. The only difference is the introduction of the feeding tube into the stomach through the gastrostomy.

Alternatively, nasojejunal intubation can be performed with the so-called over-the-wire method. First, a pediatric gastroduodenoscope or colonoscope is inserted into the distal duodenum or the proximal jejunum. Then, a Teflon-coated guidewire is

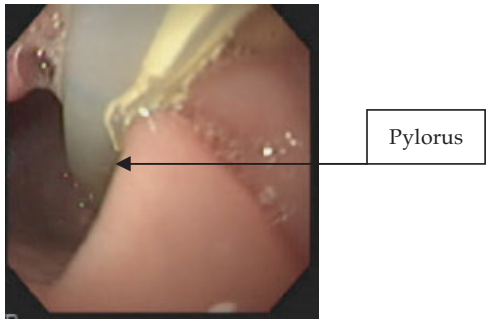


Fig. 6.24 Nasojejunal tube. The adequate position of the tube is achieved: the distal part of the tube is in the duodenum while the rest of the tube is properly positioned in the stomach.

placed in the biopsy channel and advanced a few centimeters beyond the tip of the scope. The next step involves synchronous withdrawal of the shaft and insertion of the guidewire until the endoscope is withdrawn completely. A soft lubricated tube is advanced into the oro pharynx through the nose and removed from the mouth by the index finger blindly or with the help of a plastic grasper. After that, a guidewire is inserted into the tube and rerouted through the nose.

The protective tube is removed. The final stage of the procedure is performed under fluoroscopy. A lubricated nasojejunal tube is advanced along the guidewire into the distal duodenum or proximal jejunum. The position of the guidewire and the enteral tube is adjusted under fluoroscopy.

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Practical Pediatric Gastrointestinal Endoscopy
George Gershman, Marvin Ament

7 Pediatric Colonoscopy

INTRODUCTION

Colonoscopy is a challenging procedure not only for the beginners but also for experts. The biggest obstacle is a relatively high prevalence of abnormal fixation of the descending colon, and to a lesser extent the ascending colon, which makes a colonoscopy much more difficult and occasionally impossible to complete even for experts.

However, an experienced colonoscopist is capable of managing the majority of cases successfully by using precise technique and "intuitive" sense of "upstream" colon acquired during the years of practice. On the contrary, beginners often create problems for themselves by resorting to inappropriate maneuvers, transforming a "standard," easy to navigate colon into a twisted, distended, and rigid tube. To avoid these "painful" mistakes, a trainee should become familiar with the following:

- Embryology and gross and endoscopic anatomy of the large intestine
- Main principles of colonoscopy technique
- Specific maneuvers and approaches to the "difficult" colon
- Endoscopic characteristics of common pathology

Another important aspect of training is achievement of a competence level by the trainee to perform pediatric colonoscopy safely and effectively. Although debatable, 100 diagnostic and 55 therapeutic procedures were chosen arbitrarily as a minimum requirement. An additional source of training is colonoscopy simulators, which may catalyze a learning process.

INDICATIONS FOR COLONOSCOPY

Traditionally, indications for colonoscopy are classified based upon the goal of procedure: diagnostic or therapeutic. Over the last decade, a new concept of high-volume low-yield indications has been introduced in adult practice, as colonoscopy has been used as a part of a large-scale screening program for the early diagnosis of colon cancer. A low incidence of this disease in a pediatric population virtually eliminates the needs for screening colonoscopy except for a small group of children with suspected familial polyposis coli or other rare forms of polyposis.

The indications for diagnostic pediatric colonoscopy are focused primarily on clinical symptoms: "red flags" and additional

Lower gastrointestinal bleeding • Hematochezia • Fecal occult blood
Inflammatory bowel disease • Diagnosis • Management • Extent and severity • Unclear response to treatment • Surveillance for colorectal cancer in chronic inflammatory bowel disease
Unexplained chronic diarrhea
Evaluation of anatomic abnormalities seen on barium enema
Family history of a familial polyposis syndrome
Cancer surveillance • Ulcerative colitis • Polyposis syndrome • Adenomatous or mixed polyp
Abdominal pain and chronic diarrhea in patients with HIV and other types of immunodeficiency disorders
Clinical signs of posttransplantation lymphoproliferative disorder Intraoperatively • Detection of lesions that cannot be detected on palpation and/or inspection
Therapeutic colonoscopy • Polypectomy • Treatment of bleeding, angiodysplasia • Removal of foreign body • Decompression of megacolon or colonic volvulus • Balloon dilation of stenotic lesions

Table 7.1 Indications for colonoscopy.

clues of serious pathology of the large intestine and the terminal ileum obtained from radiological and other diagnostic procedures or laboratory tests (Table 7.1). In addition, colonoscopy and biopsy are indicated for surveillance for detection of malignancy in patients with long-standing inflammatory bowel disease.

Patients who have undergone small intestinal transplantation may need to undergo ileoscopy and/or colonoscopy to obtain specimens from transplanted bowel to look for rejection, viral infection, and evidence of lymphoproliferative disease.

Diagnostic colonoscopy is not indicated in patients with

1 Acute self-limited diarrhea
2 Gastrointestinal (GI) bleeding with a demonstrated upper GI source
3 Irritable bowel syndrome

Peritonitis
Conditions with a high risk of preparation • Fulminant colitis • Toxic megacolon • Recent surgical anastomoses
Inability to visualize mucosa • Poor bowel preparation • Massive GI bleeding
Associated medical problems • Sepsis • Absolute neutropenia • Respiratory and cardiovascular distress

Table 7.2 Contraindications to colonoscopy.

4 Chronic non-specific abdominal pain
5 Constipation with or without impaction
6 Inflammatory bowel disease which is responsive to treatment

Diagnostic colonoscopy is absolutely contraindicated in anyone with fulminant colitis or toxic megacolon, suspected perforated viscous, and recent intestinal resection (Table 7.2). However, patients with acute severe colitis in which cultures are negative for bacterial pathogens and parasites, such as *Entamoeba histolytica* and *Trichurus trichura*, should have an examination of the rectum and distal sigmoid colon to help establish whether they have a specific type of colitis. In such cases, limiting the area viewed, as indicated, does not pose an undue risk. There are times when direct visualization of the mucosa gives a specific diagnosis such as when pseudomembranes or punched out ulcers are seen.

Physicians should not consider performing colonoscopy in patients who have chronic or recurrent abdominal pain without other signs and symptoms, such as weight loss, failure to grow, loss of appetite, perianal disease, or positive indicators for inflammatory bowel disease, such as an elevated sedimentation rate, increased C-reactive protein, and positive screening panel for inflammatory bowel disease.

PREPARATION OF THE PATIENT FOR COLONOSCOPY

Preparing infants and children for colonoscopy can be difficult. In children who are less than school-age, it is often very difficult to explain to them why they are asked to have a restrictive diet, and a simple explanation of why the test is being done is all

that should be provided. The physician and family should try to use words that the child will understand in order to clarify why they are going to be tested. Children simply need to be told that they are going to have a test to look at where their "poop" comes from, and it has to be clean inside to take a good look.

In school-age children and adolescents more detailed explanations may be provided depending on the level of sophistication of the child. It is useful to show the children and parents diagrams of the rectum and colon and distal small bowel to make them aware of what is going to be examined. Providing such knowledge ahead of time may make the child or adolescent more amenable to the procedure and more cooperative in preparing for the examination. They should be shown pictures of the instruments used and simple diagrams of what may be normally seen.

Children at any age should be told that they will be given an intravenous infusion through which they will receive medications to make them sleep and to minimize any pain or discomfort. Because most colonoscopists use medication to alter memory, such as Valium® or Versed®, the individuals and their families should be told that they will have little memory of the procedure other than going to sleep. They should be told that they would have little or no pain during the procedure because of the medications used to decrease their ability to sense pain.

They should be told, in preparation for the procedure, that they will have devices attached to their fingers and arms, which measure their blood pressure or how hard their heart pumps, how fast their heart is beating, and the rate at which they are breathing. They should also be told that devices would be used to tell how much oxygen is in their blood. They should be told that when they awake from sleep their parents would be nearby. This type of explanation before the procedure in most children will alleviate much of their anxiety. However, some children will not be comforted by such explanations.

During preparation the most difficult thing to do is to prepare the bowel so that it can be adequately visualized. A number of different regimes are available that are based either on wash out of the bowel (lavage) or on cathartics. Both methods are subject to failure because they rely upon the cooperation of the child and family.

Although it is debatable, we do not use any preparation of the colon in infants less than 4 months old. They have almost liquid stool, which is easy to irrigate and aspirate during the procedure. The best technique of colon preparation for infants 4–12 months of age is a combination of clear liquids and milk of magnesia. Milk of magnesia 1 cc/kg of body weight should be given two nights before the procedure and midday the day

prior to the procedure. Magnesium citrate may also be used in children above 1 year of age. This may be divided in two doses 12 hours before the colonoscopy. Some individuals become nauseated with this and other cathartics. It is often necessary to give the dose of magnesium citrate in four fractions. It is best given cold and over ice, or mixed with lemon-lime type soft drinks.

The night before the colonoscopy, a glycerin suppository can be used to enhance evacuation of the colon. This technique is probably the most benign of the methods available and is one in which the infant or child is most likely to cooperate.

If a large-volume lavage method is chosen, the patient is allowed to eat and drink up until the afternoon the day before the procedure. The patient is then asked to fast for 4 hours. A lavage solution contains nonabsorbable agents such as polyethylene glycol and electrolytes. The solutions are available flavored. The patient is given 5–10 ml/kg up to 250 ml by mouth every 10 minutes. The patient continues taking this solution until the rectal effluent is clear.

There are some adolescents and teenagers who will accomplish this preparation readily. In the younger age children, success is less assured. Hospitalization for 24–48 hours may be necessary before the procedure to cleanse the colon in uncooperative patients. If one of these solutions is used in a younger child or an uncooperative teenager, the placement of a nasogastric tube into the stomach may be the only way that one can guarantee giving the full volume of the solution.

The patient can be given metoclopramide 0.1 mg/kg to a maximum of 10 mg/20 min before the lavage is begun, to enhance or speedup gastric emptying. The patient may develop vomiting in response to the lavage. In these instances, the rate of infusion may have to be curtailed. One way that we have found that is effective in this regime is to infuse the solution continuously over a period of 12 hours. This is very effective in individuals who vomit the solution when it is given rapidly. The patient in this instance may be given metoclopramide every 4 hours to enhance gastric emptying.

If one uses the lavage technique, there should be some concern if stool is not passed within the first 4 hours. The rate of infusion is usually in the order of 100–200 ml/h up to a full volume of 4 L. We typically have an infusion going into a peripheral vein to provide maintenance fluids and electrolytes.

In recent years, low-volume nonabsorbable polyethylene glycol preparations and oral phosphosoda solution have been proven safe and effective for colon preparation in children over 2 years. Clinically significant hypernatremia or hyperphosphatemia have not been reported in pediatric patients before and

after colonoscopy. We use oral phosphosoda for children 3 years and older. The regimen consists of two doses of oral phosphosoda 7–8 hours apart the day prior to the procedure. Each dose can be divided in two or three smaller portions, as a cold drink, to prevent nausea or vomiting.

Enemas are not useful preparation for children with suspected inflammatory bowel disease since they usually cause erythema, edema, and petechiae of rectal and distal sigmoid mucosa, giving a false-positive macroscopic image.

EQUIPMENT

Different types of pediatric colonoscopes less than 12 mm are commercially available (Table 7.3). They have 3.2-mm biopsy channels, which allow the use of many accessories, such as standard biopsy forceps, snares, needles, and laser probes. Some of these colonoscopes have adjustable stiffeners. These instruments are more suitable for children 2 years and older.

Colonoscopes specifically designed for infants and toddlers do not exist. Instead, pediatric upper GI videoendoscopes can be used. It is more difficult to telescope the sigmoid colon with these instruments, but their smaller diameter prevents excessive stretching of the bowel, especially in infants.

Recently, the prototype of an ultrathin colonoscope with diameter of only 9.8 mm has been developed by Pentax Corporation (Tokyo, Japan). The preliminary results in adults showed comparable rate (96%) of cecal intubation between the standard, pediatric, and ultrathin models. The application of this type of colonoscope may be advantageous for pediatric practice especially for infants and toddlers.

	Working length (mm)	Insertion tube diameter (mm)	Biopsy channel diameter (mm)
Fujinon Corp			
EC-250 MP5	1330	11.1	3.2
EC-250 LP5	1390	11.1	3.2
EC-450 MP5	1330	11.1	3.2
EC-450 LP5	1690	11.1	3.2
Olympus Corp			
PCF-140 L	1680	11.5	3.2
PCF-160 L	1680	11.5	3.2
PCF-Q180 AL	1655	11.5	3.2
Pentax Corp			
EC-3430 L	1700	11.7	3.5

Table 7.3 Some technical parameters of new models of pediatric videocolonoscopes.

MAGNETIC IMAGING SYSTEM

A relatively high percentage of difficult colonoscopies in adults defined as failure of advancement of the tip of a colonoscope for at least 5 minutes stimulated development of a nonradiographic imaging method for reconstruction of the position, shape of the shaft within the colon, and optimal placement of manual hands supporting pressure in real time. The prototype of the system was developed in 1993 based on the principle of magnetic field position screening. The modern version of the system is commercially available as a Scopeguide (Olympus Optical Corporation). It is a portable and mobile unit, which is easy to set up and position at the site of the patient's gurney. The device produces a radiation similar to a modern TV set. The calibration process is quite simple and may be performed in less than 2 minutes. It is equipped with a three-dimensional image reconstruction processor, which imitates a spatial configuration of a special colonoscope or inserted probe during colonoscopy. A pediatric colonoscope with built-in coils for magnetic image receptive system is not currently available. The existing probe is designed for colonoscopes with 3.2-mm biopsy channel. This limits an application of the technology for infants and small toddlers. Gentle insertion of the probe is required before procedure for calibration. The optimal position of the probe just above the tip of the colonoscope is secured by a simple plastic–rubber anchoring device. The presence of the probe inside a biopsy channel diminishes the effectiveness of suction, which requires even more restriction of air insufflation compared with a standard technique. Serial images help to verify a configuration of the probe and corresponding shape of the inserted shaft (Figs. 7.1–7.3) and, more importantly, simplify the straightening of the shaft. These are also useful for trainees for faster understanding and learning of

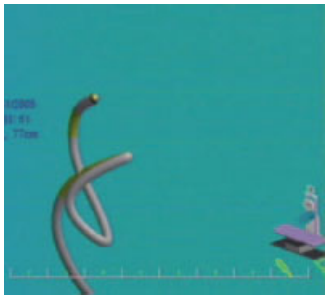

Fig. 7.1 Alfa loop. The tip of the scope is in the splenic flexure.

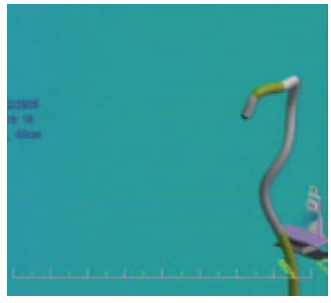

Fig. 7.2 Configuration of the scope after the Alfa loop was reduced.

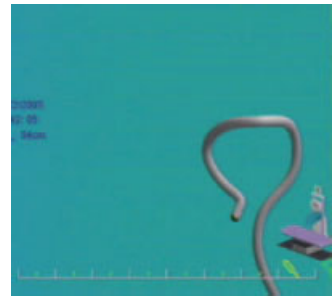

Fig. 7.3 The tip of the scope is in the cecum. There are no visible loops. The length of the inserted scope is close to the real length of the colon.

a torque-steering technique and building up skill in colonoscopy. Development of a pediatric version of the colonoscope for a Scopeguide system in the future will increase the application of this technique for pediatric patients.

INFORMED CONSENT AND PREPROCEDURE PREPARATION

The risks and benefits of the colonoscopy should be reviewed with the family at the time that the procedure is scheduled. Questions and answers about the procedure may be discussed at that time.

On the day of the procedure, informed consent is again obtained. The child and parents or guardian may be brought to the preprocedure area. In this area an intravenous infusion is started.

In order to minimize the discomfort of the intravenous needle, EMLA® cream may be applied to three or four potential intravenous sites 60 minutes before an appropriate angiocath is placed. Once the angiocath is in position and functioning well, it is secured and intravenous infusion is started. The patient is then transferred to the procedure area, where all necessary preparations for sedations are taken care of.

SEDATION FOR COLONOSCOPY

These are three options to performing a colonoscopy in pediatrics: without sedation, with sedation, or general anesthesia.

A colonoscopy without sedation is rather hypothetical but practical option. Although it is feasible in the hands of an experienced gastroenterologist in the rare case of a very cooperative patient and parents, it is not a common practice in the United States and Europe.

Pediatric colonoscopy is routinely performed under sedation or general anesthesia. Usually, an anxious and scared child does not allow even digital rectal exam or proper positioning on the gurney until deeply sedated. The definition of deep sedation includes the following:

- Patient is responsive only to painful stimuli
- Spontaneous breathing
- Presence of deep tendon reflexes

General anesthesia with commonly used medications such as Ketamine® or Propofol® is not principally different from deep sedation but requires a skillful anesthesiologist in case of complications or need for endotracheal intubation. On the contrary, a pediatric gastroenterologist providing a deep sedation should be capable of endotracheal intubation. The logistics of the choice usually depends on the specific policy of an individual

institution, availability of an anesthesiologist, and economics of a particular medical practice.

The advantages of general anesthesia with Propofol are quick induction time, minimal side effects, and short stay in recovery rooms, which are attractive for pediatric gastroenterologists especially in private practice. It also may decrease the turnover time of each procedure and increase potential revenue. On the other hand, a higher cost of routine colonoscopy under general anesthesia may not be covered by all insurances.

The goal of any sedation for colonoscopy in children is maximal elimination of anxiety and pain during the procedure with minimal risk of complication. Anxiety is relatively easy to overcome in majority of children by appropriate dose of tranquilizers. Pain control is a more complicated and controversial part of the sedation. It is important to accept that pain during colonoscopy is always related to a loop formation and stretching of the colon. A general rule is that the more skillful the endoscopist, the less analgesics are required for sedation.

There is a real concern that deep sedation, and especially general anesthesia, masks patient discomfort and stimulates excessive activity by the less experienced endoscopist, which may lead to overstretching of the sigmoid colon and increase the risk of complications. Again it is important to accept the concept that a sedated patient with slight discomfort is comparable to a screaming nonsedated child. It is wrong to give an extra dose of anesthesia and/or tranquilizer to overcome this warning sign in order to make some progress with bowel intubation. It is a good practice to stop and reassess the position of the colonoscope, and to make some adjustments to reduce the loop before further advancement. It is important to remember that it is better to abort a colonoscopy rather than increase the risk of complications. Once again, a refined technique of colonoscopy should be considered as an important part of pain control.

Following sedation the patient is placed in the left lateral decubitus position. The parents are asked to leave the room once the patient is sedated.

EMBRYOLOGY OF THE COLON

Abnormal rotation and fixation of the embryonic colon is probably the major reason for a difficult colon and incomplete colonoscopy. The rotation of the primitive large intestine begins when the embryo is only 10 mm long. It occurs as a result of elongation of the intestinal tube, separation of the yolk stalk, and stepwise herniation of the duodenojejunal loop into the umbilical cord.

A counterclockwise rotation around the superior mesenteric artery is the main mechanism of "packaging" the growing

intestine in preparation for its return back to the abdomen. At a stage of a 25-mm embryo, almost the entire intestine is within the umbilical cord. When the embryo grows to 40 mm in length, there is enough space in the abdomen to accommodate the small and large intestine.

Additional counterclockwise rotation is again crucial for proper relocation of the intestine into the peritoneal cavity. As a result the cecum swings to the right hypochondric area above the superior mesenteric artery. At the end of rotation, the cecum migrates down to the right iliac fossa. Finally, the mesentery of the descending and ascending colon fuses with the posterior peritoneum and disappears being pushed back by heavy loops of the small bowel.

In normal circumstances, the cecum also does not have a mesentery because it is an outpouching of the antimesenteric aspect of the ascending colon. Its incomplete posterior fixation allows some mobility of the cecum, which does not create any problems for colonoscopists unless the patient has a mobile cecum.

The rectum is derived from the cloacae and fuses with the sigmoid colon by the eighth week of gestation and has some but limited mobility.

Thus as a result of a normal rotation, the colon acquires two zones of full fixation – the descending and ascending colon – as well as two areas of partial fixation – the cecum and rectum. In addition, the mobility of the splenic and hepatic flexure is somewhat limited by a phrenocolic ligament and the extension of the hepatorenal ligament, respectively. Only the sigmoid and transverse colons possess their own mesentery and are fully mobile. It is not surprising that they became a target of various endoscopic maneuvers preventing or minimizing stretching of these vulnerable segments of the intestine.

It is easy to imagine that abnormal rotation or fixation of the embryonic colon can multiply difficulties in telescoping of an unusually mobile bowel. As a rule, this is a total surprise for the endoscopist. Some of the anomalies can be suspected during a procedure, e.g., fixation of the cecum in the right hypochondrium.

The intrinsic property of the embryonic colon to move from the left iliac fossa to the right one as the result of a counterclockwise rotation gives an important clue to understand the concept of a torque-steering technique of a colonoscopy.

In general, counterclockwise rotation of an endoscope creates some deviations of the sigmoid colon to the right flank of the abdomen. The degree of sigmoid stretching is proportional to the length and plasticity of the attached mesentery and amount of force applied to the colonoscope to push it forward or rotate it counterclockwise. Thus a stretching and looping of the sigmoid colon should be anticipated during counterclockwise

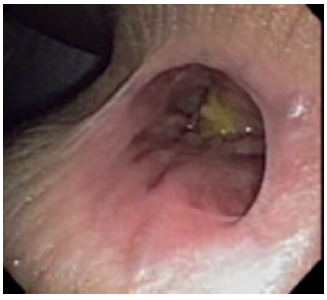

Fig. 7.4 Unusually wide-open anus. This finding is suspicious for spina bifida, trauma, or sexual abuse.

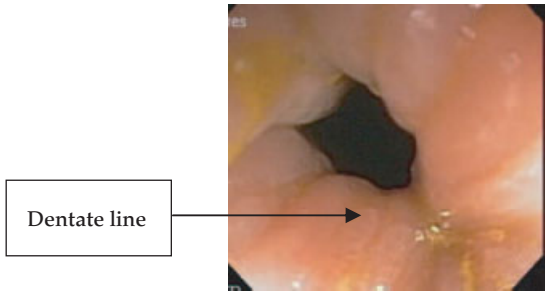

Fig. 7.5 Squamocolumnar junction or dentate line.

rotation of the endoscope. To the contrary, clockwise rotation of the endoscope moves the colon to the left and helps to telescope the sigmoid colon and minimize stretching and loop formation.

ENDOSCOPIC ANATOMY

The anal canal is less than 2 cm in a newborn, reaching an adult length of 3 cm by 4 years of age. It is normally closed due to a tonic contraction of the anal sphincter. If it is constantly open or if sphincter tone is substantially decreased, spina bifida, trauma, or sexual abuse should be ruled out (Fig. 7.4). It is important to remember that an axis of the anal canal is pointed anteriorly. Proper insertion of the colonoscope will prevent the discomfort due to excessive pressure and disorientation in the distal rectum due to imbedding of the tip into the rectal mucosa.

The proximal edge of the anal canal is demarcated by a squamocolumnar junction or pectinate (dentate) line (Fig. 7.5). Few longitudinal folds (the columns of Morgani) run within the anal canal and terminate at anal papillae (Fig. 7.6). Occasionally,

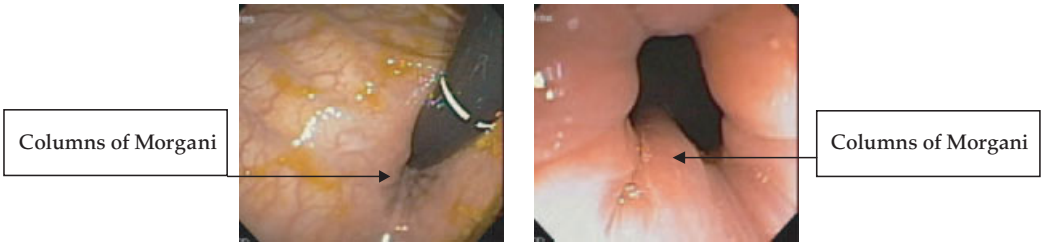

Fig. 7.6 The longitudinal folds in the distal rectum (the columns of Morgani) and enlarged anal papilla. The u-turn maneuver in the rectum is useful for detail observation of the distal rectum close to the anal canal.

anal papillae may be quite prominent, cone like grayish structures. The rectum becomes enlarged and fusiform between the upper edge of the columns of Morgani and the rectosigmoid junction. This part of the rectum is called an ampulla. It is marked by three semilunar folds referred to as valves of Houston (Fig. 7.7). There are two such folds on the left and one on the right lateral wall. The ampulla narrows at the level of rectosigmoid junction, which is distanced from the anal verge by 9 cm in neonates and 15 cm in children 10 years and older. The rectal mucosa is smooth and transparent and allows a good visualization of submucosal veins (Fig. 7.8).

Multiple small lymphoid follicles on the rectal mucosa are normally present in infants and toddlers. Scattered follicles less than 3 mm can be seen in older children.

The sigmoid colon is the most "unpredictable" part of the colon due to its long, V-shaped mesocolon. Stretching during colonoscopy could double the length of the sigmoid colon. Therefore, an absolute length of the sigmoid colon is not so important unless it is tremendously elongated.

The mobility and displacement of the sigmoid colon could be limited due to previous surgery, adhesions, or shortening of the mesentery.

A relatively small sigmoid colon in infants and toddlers has some disadvantages for the endoscopist:

First, it decreases a threshold for pain during stretching and limits an application of standard pediatric colonoscopes secondary to the relatively large radius of curvature.

Second, it makes it impossible to perform the alpha loop maneuver, leaving no choice but precise telescoping of the sigmoid colon without any room for even small technical mistakes.

The normal sigmoid colon appears tubular due to the prominence of a circular muscle layer. The mucosa is less transparent than in the rectum. There are multiple circular folds throughout the sigmoid colon (Fig. 7.9).

The teniae coli are usually not visible along the sigmoid colon except on the area adjacent to the sigmoid–descending junction. The appearance of teniae coli in this area indicates significant stretching of the sigmoid colon.

During colonoscopy, the sigmoid colon is "shaped up" in somewhat predictable fashion. It becomes more spiral and twisted clockwise between the posteriorly located rectum and descending colon. The concave sacrum and a forward-projecting sacral promontory determine the initial anterior deviation of sigmoid loop. At this stage of the procedure, a colonoscope can be palpated easily unless the sigmoid colon is extremely stretched.

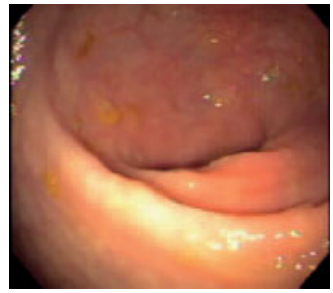

Fig. 7.7 Semilunar folds of Houston in the rectum.

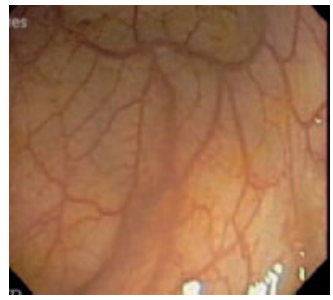

Fig. 7.8 Typical vascular pattern of the normal rectum.

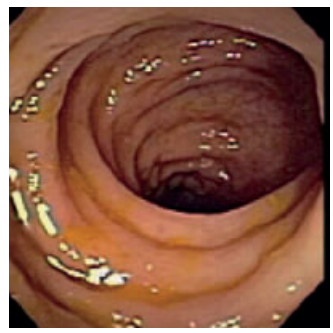

Fig. 7.9 The sigmoid colon. The endoscopic markers of normal sigmoid colon are (i) rounded lumen, (ii) circular folds, and (iii) subtle vascular pattern.

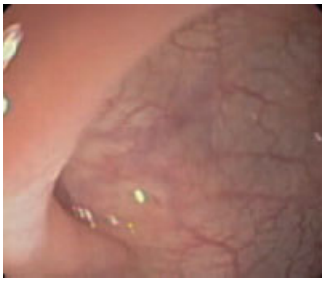

Fig. 7.10 The angle is sharper when the descending colon extends down below the pelvic brim due to unusually low fixation and/or when the sigmoid colon was stretched out extensively.

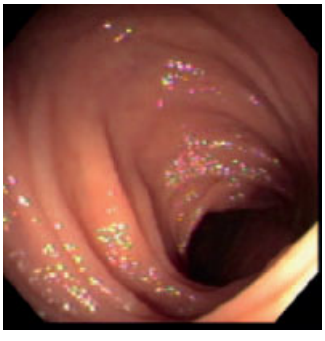

Fig. 7.11 The descending colon. The descending colon is oval in shape.

In children, palpable loop can be reduced or modified by an assistant in coordination with withdrawal maneuver performed by the endoscopist.

The transition zone between the sigmoid and ascending colon is usually located at the level of pelvic brim. It is rather an endoscopic as oppose to anatomic entity. Sharp angulation occurs usually secondary to twisting and stretching of the sigmoid colon. The angle is sharper when the descending colon extends down below the pelvic brim due to unusually low fixation and/or when the sigmoid colon was stretched out extensively (Fig. 7.10).

Once the endoscope is passed through the junction between the sigmoid and descending colon, the "surprises" are usually over unless the patient has lax phrenocolic ligament or persisted mesocolon of the ascending colon.

Normally the descending colon is relatively short, about 10 cm in infants and 20 cm in toddlers. It is slightly wider and more oval than the sigmoid colon (Fig. 7.11). It runs straight up toward the left hypochondrium to joint the splenic flexure. The mucosa of the descending colon appears grayish.

The stems of the vessels run along the folds, i.e., perpendicular to the lumen. The small branches spread around and across the folds (Fig. 7.12). It may help to verify the axis of the colon without a panoramic view of the lumen, when pulling back is limited by extensively twisted bowel, which could untwist during the withdrawal maneuver.

The folds of the descending colon are spread more apart relative to the folds of the sigmoid colon. The teniae coli are usually not visible. These minor endoscopic changes help to verify the position of the shaft in the descending colon during the advancing phase of colonoscopy.

The splenic flexure is marked by the bluish color of the transilluminated spleen (Fig. 7.13). This area should occupy the right part of the lumen if the colonoscope was positioned properly inside the sigmoid and descending colon. The same color spot can be seen occasionally when the tip of a colonoscope is trapped

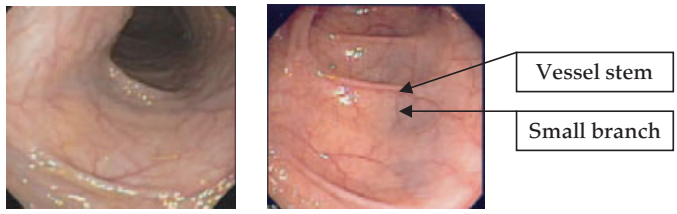

Fig. 7.12 The vascular pattern of the descending colon. The stems of the vessels run along folds, i.e., parallel to the lumen. The small branches spread around and across the folds and along the lumen.

within a very large sigmoid loop. Thus this color mark does not definitively prove that the splenic flexure has been reached.

The splenic flexure is firmly attached to the diaphragm by the phrenocolic ligament at the level of tenth and eleventh ribs. That could explain occasional hiccups and transient hypoxia during exploration of the transverse colon due to excessive pressure and irritation of the phrenic nerve especially in infants and young children.

The junction with the transverse colon is located along the upper aspect of the medial wall of the splenic flexure. It is "naturally" angled by the mobile transverse colon, which hangs down from the elevated splenic flexure. The junction is more sharply angled and even folded when the patient is in the left lateral position (Fig. 7.14).

The transverse colon is relatively short in children. It is about 14 cm in newborns and 30 cm in 10-year-olds, which is a big help during pediatric colonoscopy. Relatively thin circular rather than longitudinal layers of the muscularis propria are responsible for the triangular shape of the transverse colon (Fig. 7.15).

The slope of the transverse colon is pointed toward the hepatic flexure. It is more voluminous than the adjacent colonic segments and has a blue-gray color acquired from the neighboring liver (Fig. 7.16). The folds are circular at both ends of the hepatic flexure. They are less prominent at the apex.

The junction between the hepatic flexure and the ascending colon is located higher than that between the hepatic flexure and

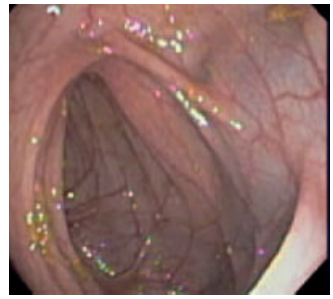

Fig. 7.13 The splenic flexure. It is marked by bluish discoloration.

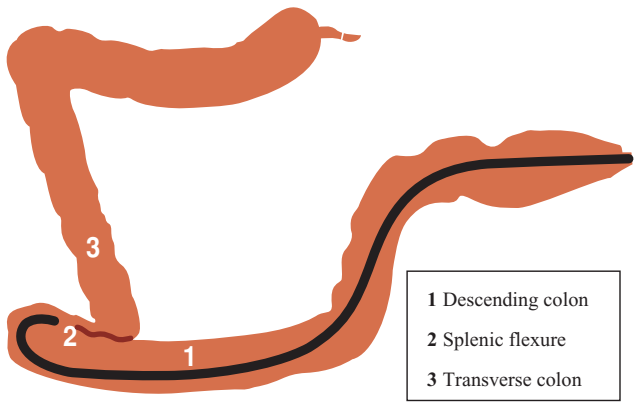

Fig. 7.14 The relationship of the angle between the descending colon and the splenic flexure and the position of the patient during colonoscopy. The irregular configuration encountered at the splenic flexure and adjacent descending colon is created by the transverse colon, which is hanging down during colonoscopy when the patient is in the left lateral position.

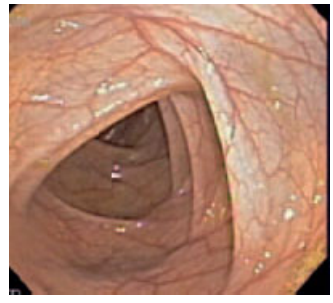

Fig. 7.15 The transverse colon. The triangular shape is the endoscopic hallmark of the transverse colon.

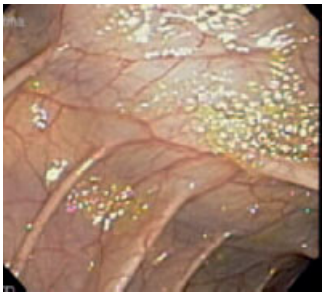

Fig. 7.16 The hepatic flexure. The mucosa of this area is paler and has light bluish tinge acquired from the adjacent liver.

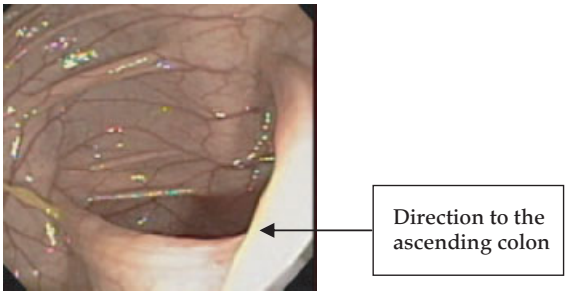

Fig. 7.17 The hepatic flexure. It is dome-shaped. The junction between the hepatic flexure and the ascending colon is always hidden in the right upper corner of the screen behind the mucosal fold. Steering of the shaft counterclockwise, pulling it back, and elevation of the tip help to stretch the folded lumen. Subsequent clockwise rotation and deviation of the tip to the right and decompression of the colon facilitate exploration of the ascending colon.

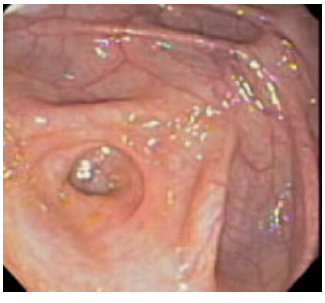

Fig. 7.18 The appendiceal orifice.

the adjacent transverse colon. It points toward the right lobe of the liver and is sharply angled posteriorly (Fig. 7.17).

The ascending colon is a short, retroperitoneal, and fixed segment of the right colon. It runs between the cecum anteriorly and the lower pole of the right kidney posteriorly. The lumen of the ascending colon is wide and constantly opened. It terminates as a "blind" pouch cecum, which has two landmarks:

- appendiceal orifice and
- ileocecal valve

The appendiceal orifice is usually oval or rounded (Fig. 7.18) and is located at the intersection of the teniae coli. The ileocecal valve is situated at the posterior medical aspect of the cecum. It usually stays aside from the forward-oriented optical system of a colonoscope. That is why it is only partially seen as a focal widening of the circular fold (Fig. 7.19).

In the newborns, the cecum is cone-shaped, with the appendix in the middle. Later on, the cecum expands sideways by unequal enlargement of the haustra: a lateral sac becomes more spacious

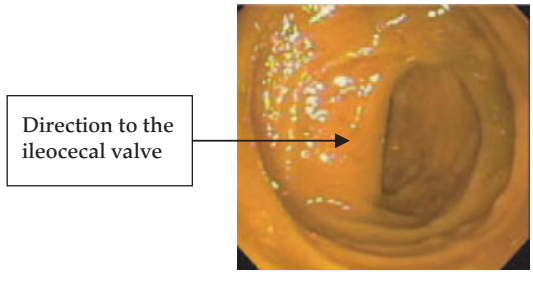

Fig. 7.19 The ileocecal valve. A focal widening of the circular fold in the cecum is the sign of the hiding ileocecal valve.

than the medial one. Thus the cecum assumes an eccentric shape. The thickness of the cecal wall is the smallest along the colon, which should be kept in mind during polypectomy.

TORQUE-STEERING TECHNIQUE

A special colonoscopy technique has been developed to overcome high flexibility, elasticity, and multiple angulations of the large intestine (the sigmoid colon in particular). The main principle of this technique, often called torque-steering technique, is a substitution of a corkscrew maneuvering around an angled segment of the colon for pushing forward approach, which leads to a loop formation.

Following are the elements of the technique:

- Rotation around bended colon segments instead of pushing up against them
- Slow rather than rapid start of each maneuver with a colonoscope
- Frequent pulling back for shortening the sigmoid and transverse colon and straightening of twisted segments of the large intestine
- Prediction rather searching for a lumen
- Pulling back when orientation is lost
- Ascertainment of a correct axis of the colon before manipulations with a colonoscope (this is much more important for progress than search for a fully opened lumen)
- Substitution of clock- or counterclockwise torque and up and down angulations for manipulations with the R/L knob
- Utilization of the R/L control knob as little as possible (knob-induced tip deflection gets less and less effective with advancement of the shaft)
- Avoidance of full angulations of the tip. It will not slide along the colon
- Anticipation of a spring effect of twisted colon and prevention of spontaneous untwisting of coiled segment by repeated clock- and counterclockwise rotations
- Programmed rotation of the lumen: the colon usually moves in an opposite direction to the rotation of a shaft
- Minimize insufflations: excessive air in the colon makes it ridged and elongated
- Frequent air suction and infrequent suction of fluid

Sharing "inherited" similarity, pediatric colonoscopy is not a traditional colonoscopy for a small patient. The most important difference in technique of colonoscopy between adult and children is a low efficacy of an "Alfa" maneuver and more detrimental effect of a loop formation for children, especially the younger ones. The rule of thumb is that the younger the child, the more difficult to bypass the sigmoid–descending junction if a big loop occurred.

Handling a colonoscope: There are two ways to perform a colonoscopy:

- By the endoscopist managing all manipulation with a control panel and the shaft with the left and right hand, respectively (one person – single-handed approach).
- By the endoscopist working with the control panel and the assistant handling the shaft according to the endoscopist's orders. (two persons – two-handed approach).

It is generally accepted that one-person single-handed technique is the most effective way to conduct a colonoscopy. The benefits of this approach are:

- Precise control of an entire colonoscope
- Coordinated activity of the left-hand-operated up/down control knob and the right-hand-rotated shaft
- Almost immediate response to a changing position of the colon
- Constant assessment and control of the bowel resistance
- An ability to prevent unwinding of the telescoped bowel

A colonoscope is held similar to an upper GI videoendoscope (see Chapter 5). Attention should be paid to a constant grip of the shaft by the right thumb and by index and middle fingers. The intensity of grip varies from light to firm with continuous rotation. A common mistake of the beginner is to lose hold of a shaft with an attempt to use an R/L control knob. A released shaft untwists immediately, allowing the bowel to escape from telescoped and straighten condition.

A three-finger rotation technique is the most effective way to torque a colonoscope for a full 360°. An additional 180° rotation can be achieved by moving a wrist in clock- or counterclockwise direction.

If continuous rotation is needed, an assistant can hold the shaft while the endoscopist adjusts a grip. Alternatively the endoscopist moves a left arm with the control panel within the forth and fifth fingers under the right arm, squeezes the shaft tight between the index and middle fingers and the control panel, and then adjusts the grip of the right hand without "loosing" a telescoped bowel. A colonoscope should be maximally straightened to optimize transmission of the rotating force from the control panel to the shaft. It can be achieved by keeping an appropriate distance between the child and the endoscopist and repeat pulling back maneuvers. One of the common mistakes of the beginner is holding the shaft too close to the anus. Grasping a colonoscopy to the level of 20–25 cm from the tip decreases the need for frequent changes of handgrip and facilitates an application of torque and control of rotation.

Position of the patient and insertion technique: Traditionally, colonoscopy is performed with the patient in the left decubitus position. The child's head is resting on a small firm pillow. The arms are relaxed along the torso; left leg is stretched while the

right bended leg is positioned across the left one. It protects the patient from accidentally rolling back or turning prone.

The insertion of the colonoscope into the rectum and control of the shaft is easier when the patient is in the left decubitus than in the supine position. In addition, if the child is placed close to the endoscopist's side of the gurney, the shaft hangs down and can be kept in the desired position, by trapping it between the endoscopist's right thigh and the edge of the gurney without being held. There are three disadvantages of the left decubitus position:

- Less precise control of the sigmoid colon, which is easier to palpate and support by hand pressure when the patient is supine
- The sigmoid colon tends to crumple down toward the left flank, making the transition into the descending colon more angled and difficult to bypass
- The transverse colon flops down and narrows the connection with the splenic flexure

Thus, a procedure could be started with the child in the left decubitus position, and then the patient can be turned supine when the sigmoid–descending junction is approached. Alternatively, a supine position can be used from the beginning of colonoscopy in infants, toddlers, and preschool children.

Insertion technique: Before insertion, the entire equipment and suction system should be checked for proper function. A gurney is lifted to the height comfortable for the endoscopist. The distal 20 cm of the shaft is lubricated. A rectal exam prior to the procedure serves two purposes:

- Lubrication of the anal channel
- Reassurance that the patient has been adequately prepared and sedated

If there are any doubts about the quality of bowel preparation, a rectal exam should be performed before sedation to avoid unnecessary exposure to medication.

The assistant gently lifts up the right buttock to expose the anus. The endoscopist grips the shaft at 20–30-cm marks, positions the tip into a gentle contact with the anus, and aligns the bending portion of the shaft with the axis of the anal channel, which runs toward anterior abdominal wall. Insufflation of the anal canal and slight clockwise torque of the shaft facilitate sliding of the tip into a distal rectum with minimal pressure. This technique virtually eliminates any pain or accidental trauma of the distal rectum. Right after initial exploration of the rectum, a colonoscope is pulled back slightly and angled upward to establish a panoramic view of the rectal ampulla. Any liquid stool can be easily aspirated to simplify the approach to the distal rectum. Do not aspirate semiformed stool at the beginning of colonoscopy to avoid problems with the suction channel. It will lead to overinflation of the colon with air and difficulty in completing a total colonoscopy. After that the colonoscope is

advanced toward the rectosigmoid area. It is distant from dentate line for about 10–15 cm. This is the first but not the last time when the lumen may disappear.

Endoscopic clues of a hidden lumen: In order to reach the splenic flexure reasonably quickly, it is important to accept the concept that a constant search for a full lumen is not a productive way to conduct colonoscopy. It creates more problems than benefits for the endoscopist and the patient. First of all, it is not possible because many segments of the colon, especially the sigmoid colon, are sharply angulated during exploration. Second, a long opened upstream segment of the sigmoid colon indicates a big loop formation and should be avoided. Third, an extensive search for a fully open lumen leads to overinflation of the colon, which makes it ridged and elongated. Distention of the colon induces discomfort and pain, leading to oversedation and increased risk of complications. Instead, the endoscopist should not waste time searching for a full lumen but concentrate on an effort to recreate the axis of the upstream colon and the way to approach it.

In general, intubation of the colon and the sigmoid colon in particular creates clusters of sharply angled and bent segments, which have a saw-tooth pattern. It means that the axis between two adjacent colonic segments runs in opposite directions; e.g., if the visible segment climbs up diagonally from right to left to 11 o'clock, the following segment falls down in the opposite direction toward 5 o'clock.

This rule helps to accept the concept that initial position of the twisted lumen gives a clue to a pattern of colonic "behavior" and direction for steering until a sharply angulated segment sets the endoscopist off track. Disappearance of the lumen can be explained by unequal shortening of the mesenteric and antimesenteric edges of the sigmoid colon during rotation and pulling back maneuvers and positioning of the tip close to the mucosa with sudden loss of orientation.

Two strategies are useful in these circumstances:

- Search for a hidden lumen and colonic axis using endoscopic clues
- Simply pull back slowly

A narrowed slot-like or dimpled lumen of a twisted colon is usually located in three areas: between 10 and 12 o'clock, 1 and 3 o'clock, or 4 and 6 o'clock (Fig. 7.20). Another clue to an obscure lumen is converging folds pointed to the slightly depressed, grove-like area (Fig. 7.21). It is useful to remember that main submucosal vessels are parallel to circular folds. However, their small branches are usually spreading around between the folds and can highlight the axis of the lumen (Fig. 7.22).

When the tip is close to the sigmoid–descending junction, a prominent tenia coli or a center of the convex folds indicates a direction of the colonic axis and the location of the next segment (Fig. 7.23).

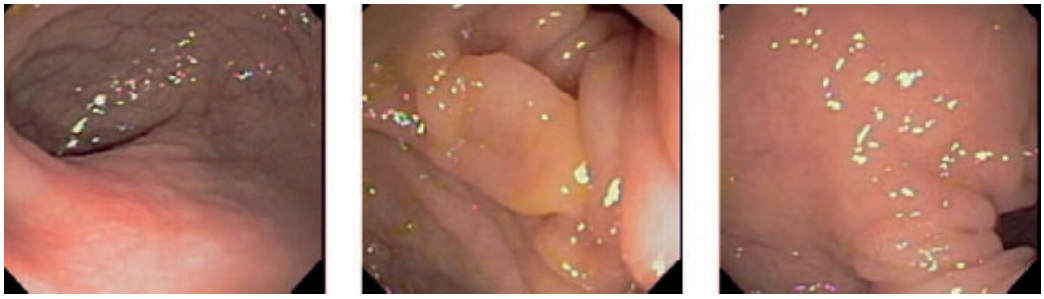

Fig. 7.20 Common locations of the lumen. The left image: the lumen is located at 9 o'clock; the middle image: the lumen is between 1 and 2 o'clock; the right image: the lumen is located at 5 o'clock.

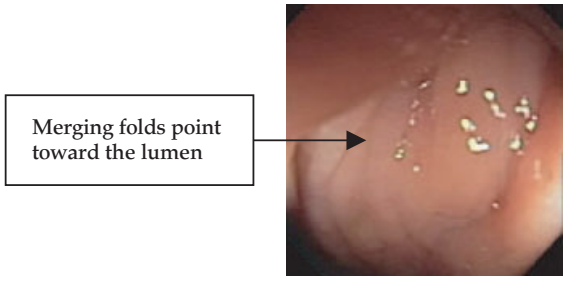

Fig. 7.21 Slightly depressed groove-like area and merging folds are the signs of the hidden lumen.

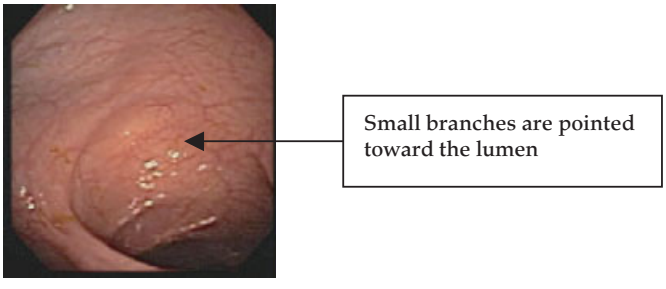

Fig. 7.22 The main submucosal veins and their branches. The main vessels are parallel to the circular folds. The small branches are pointed toward the lumen. This endoscopic clue may be useful when the tip of the scope is distant from the mucosa for at least 1 or 2 cm.

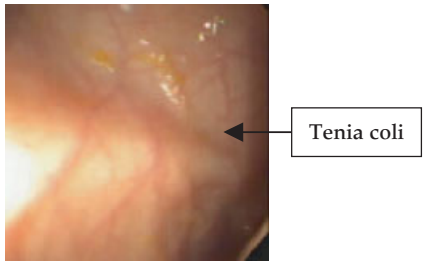

Fig. 7.23 Prominent tenia coli. An appearance of the tenia while approaching the sigmoid–descending junction indicates the presence of the significant loop in the sigmoid colon.

The following is a description of the corkscrew technique, which is particularly useful for sliding through the sharply angled segments of the sigmoid colon and sigmoid–descending junction:

- Orient the tip toward a narrowed lumen and advance the shaft forward slowly. If the lumen is located at 11 o'clock, rotate the shaft counterclockwise and angle the tip up. As soon as the edge of the lumen is approached, rotate the shaft clockwise and pull it back. If the lumen is located between 4 and 6 o'clock, rotate the shaft clockwise and pull it back. It will untwist the lumen and facilitate sliding of the tip into the proximal segment of the colon. If the next segment is straight, advance the shaft a few centimeters forward. Rotate it clockwise and pull it back to telescope (shortening) the colon. Repeat this maneuver several times until the sigmoid–descending junction is reached. This technique is equally applicable to the rectosigmoid area and the junction between the splenic flexure and the transverse colon.

EXPLORATION OF THE SIGMOID COLON AND SIGMOID–DESCENDING JUNCTION

The sigmoid colon is the most vulnerable part of the large intestine. It is not as long in children as in adults. However, children especially infants and toddlers are less tolerant to stretching of the sigmoid colon. A relatively short mesentery is less elastic, which decreases the threshold for pain.

Nevertheless, in deeply sedated infants and toddlers, a less experienced endosocopist can create a huge loop which is not palpable through the abdominal wall because it occupies both lateral gutters and pushes up against the liver and left diaphragm. It may create a false impression of a properly performed procedure without significant loop. The clinical clues to this dangerous condition are sudden changes in oxygen saturation, hiccups, shallow breathing, and irritability of the patient, followed by signs of respiratory distress. Immediate reduction of the loop and interruption of the procedure is mandatory until the child becomes stable.

During exploration of the sigmoid colon small loops are unavoidable, but easily reducible and are considered a routine part of the procedure. However, formation of the larger loops should be prevented.

There are several clues to recognition of clinically significant loops:

- Discomfort and pain
- Long tubular segment of the bowel ahead
- Loss of "one-to-one" relationship between pushing of the colonoscope and advancement in the colon

- Paradoxical movement of the lumen away from the tip with attempts to advance the shaft
- Increased stiffness of the angulations control and increased resistance to the shaft

The elements of the most effective technique for preventing a big loop from forming are:

- Corkscrew sliding around sharply angled colonic segments
- Establishing an appropriate angle for corkscrew sliding maneuvers
- Avoidance of forceful advancement (push through a significant resistance)
- Frequent pulling back with simultaneous clockwise rotation of the shaft
- Minimal insufflations
- Transabdominal hand pressure support of the sigmoid colon
- Changing the patient's position

The presence of a big loop is a sign of two possible scenarios:

- Formation of a large "N" loop
- Existence of a large Alfa loop or atypical loops

The second variant is less likely in children. In any case, it is reasonable to assume that the tip is in close proximity to the sigmoid–descending junction. A supporting endoscopic sign of this location is a prominent tenia coli pointed toward the right upper corner of the screen. It is worse trying to turn this undesirable situation into your favor. For successful reduction of a sigmoid loop and advancement of the tip into descending colon, proceed with the following:

First, turn the patient to the back to decrease the sharpness of the sigmoid–descending junction.

Second, try to palpate the dome of the loop and show your assistant how to support it. If the dome of the loop is in the right part of the abdomen, an Alfa loop is most likely formed. If a loop is palpated in the left part of the abdomen, an N loop has most likely been created.

Third, in case of an Alfa loop scenario pull the shaft back slowly and rotate it clockwise. The assistant should feel the loop constantly and push it gently toward the left hypochondrium synchronously with the endoscopist's maneuvers. Atypical loop should be suspected if the lumen slips away from the tip. Stop withdrawing; move the shaft to the initial position and then pull it back slowly with simultaneous vigorous counterclockwise rotation. Significant reduction of resistance and effective withdrawal of at least 20–30 cm of the shaft with a stable position of the tip is a sign of successful loop reduction. If the N loop is suspected, locate and support the loop with hand pressure, rotate the shaft clockwise until the lumen opens up and the slightly grayish mucosa of the descending colon appears on the screen. Pull the shaft back slightly until the ridge of the

next bent segment is reached; rotate the shaft clockwise and advance it forward when a reasonably long segment of the descending colon appears. At this point the shaft is advanced deep into the descending colon and is stable enough to complete the reduction of the N loop by pulling the shaft back. In the majority of cases the sigmoid colon is explored without a big loop. During shortening and rotation maneuvers the bowel becomes twisted and creates enough force to untwist spontaneously and slip away from the shaft. The likelihood of this undesirable effect increases when the tip is very close to or inside the junction between the sigmoid and descending colon. All manipulation with the shaft should be very careful, slow, and sequential. As mentioned above, the supine position reduces a sharp angle of the sigmoid–descending colon junction. Hand-pressure stabilization of the sigmoid colon is very appropriate for the moment. The key for success is a vigorous clockwise rotation, which facilitates sliding of the tip into the descending colon. If an additional segment is located ahead at 11 o'clock, pull the shaft back slowly, elevate the tip up above the edge of the fold, and rotate the shaft clockwise until a wide-open oval lumen of the descending colon appears. Then advance the shaft and align the tip with the axis of the upstream segment. The lumen of the descending colon is more oval, compared to the sigmoid colon. The folds are less frequent, the color is more grayish, and the vascular pattern is more prominent. Once the descending colon is reached, advance the shaft quickly to the level of the splenic flexure. It is one of the easiest steps of colonoscopy if the shaft is fully straight and the descending colon is normally fixed in retroperitoneum.

SPLENIC FLEXURE AND TRANSVERSE COLON

In order to straighten the sigmoid colon, and untwist the external portion of the colonoscope, the shaft should be rotated counterclockwise. Attention should be given to the lumen of the bowel in odder to avoid laceration of the mucosa by the tip of the colonoscope. This maneuver facilitates an exploration of the splenic flexure.

To simplify the entrance into the transverse colon, pull the shaft back gently, rotate it counterclockwise, and angle it toward 11 o'clock. Initially, the lumen of the transverse colon appears as a slot along the line between 7 and 11 o'clock. An additional deflection in the same direction and counterclockwise rotation make the lumen wider. At this point, rotate the shaft clockwise to a quarter turn and bring the tip down slowly. It is necessary to turn the shaft counterclockwise again and elevate the tip up

before pushing the shaft into the transverse colon. Exploration of the transverse colon does not require forceful advancement of the colonoscope. In the absence of visible progress or in case of increasing resistance, pull the shaft a few centimeters back while keeping the lumen opened, and then elevate the tip and push it forward, applying clockwise torque simultaneously. Repeat this maneuver two or three times. If no significant progress has been made, rotate the patient into right lateral position, straighten the colonoscope by pulling it back, apply pressure to stabilize the sigmoid colon, and advance the shaft forward. Decreased resistance and progression of the tip forward indicate successful exploration of the transverse colon, which has a distinctive triangular lumen. At this point, the hepatic flexure can by reached almost momentarily by either pulling the shaft back with simultaneous counterclockwise rotation or pushing it gently forward.

It is extremely unlikely to create a so-called "gamma" loop in pediatric patients. The formation of this loop manifests by increasing resistance and paradoxical movement of the proximal transverse colon away from the tip, with attempts to push the shaft forward. Successful reduction of a gamma loop can be challenging. First, rotate the patient to the back, and then pull the shaft back and rotate it counterclockwise intensively. If the tip remains stable during the withdrawal phase of the maneuver, continue pulling back until the shaft is straightened. It is possible that after initial counterclockwise rotation a clockwise torque should be tried.

HEPATIC FLEXURE, ASCENDING COLON, AND CECUM

Exploration of the hepatic flexure may be challenging for beginners. It is important to remember that the axis of the hepatic flexure has a reverse gamma configuration. The entrance to the area is always located at an 11 o'clock position. A vigorous search in the wrong direction may induce pain secondary to pressure and distention of the bowel, small mucosal trauma, or retroflexion of the bent portion of the colonoscope. The correct approach to the hepatic flexure consists of few steps: (i) *Orientation*: The transitional area between the transverse colon and the hepatic flexure often appears as a blind pouch. The right part of the pouch is convex with few circular folds creating an illusion of the lumen. The left wall of the pouch is short due to rotation and spiral configuration of the bowel. Attention should be focused on the upper portion of this area. (ii) *Withdrawal*: Pull the shaft back slowly and orient the tip to the 11 o'clock direction. Continue withdrawing and deflection of the tip in the same direction until the lumen starts to open up with an initial slot-like appearance. (iii) *Decompression*: Decompress the bowel until the

lumen begins to collapse. (iv) *Switching direction*: Rotate the shaft clockwise and move the tip to the right and slightly down using the R/L knob. (v) *Advancement*: Advance the shaft forward and adjust the position by counterclockwise rotation and elevation of the tip, enough to keep it in the center of the lumen.

TERMINAL ILEUM

The ileocecal valve is tucked behind the folds. It is usually located between the 9 and 11 o'clock position (Fig. 7.24). However, occasionally it could be found in the lower aspect of the cecum between 5 and 7 o'clock position (Fig. 7.25). The ileocecal valve appears as a lip-shaped thickening of the mucosal fold. An exploration of the terminal ileum begins with detection of the ileocecal valve by pulling the shaft away from the appendiceal orifice. Once the valve is located, the tip is moved forward closer to the appendix. The following steps should be adjusted to the actual position of the ileocecal valve. If it is located at 11 o'clock, the endoscopist should (i) decompress the cecum, (ii) orient the tip to 11 o'clock, and (iii) slowly pull the shaft back until the tip slips into the terminal ileum. The position of the ileocecal valve between 5 or 7 o'clock dictates bending the tip down and to the right toward the target, clockwise rotation, and pulling the shaft back. Successful exploration of the terminal ileum is manifested by the change in color and texture of the mucosa; while the cecum appears gray and smooth with prominent vessels, the terminal ileum is pink with a slight yellow tinge and velvet mucosa with multiple small (less than 3 mm) lymphoid follicles (Fig. 7.26).

The mucosal pattern of the colon is best evaluated as the instrument is slowly withdrawn. However, some stretching of the bowel during advancement of a colonoscope makes the circular

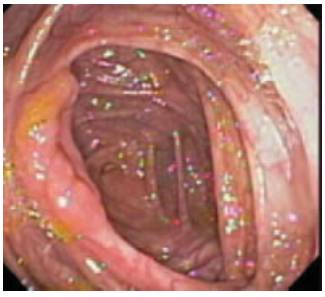

Fig. 7.24 The ileocecal valve. It is usually located between the 9 and 11 o'clock position of the cecum.

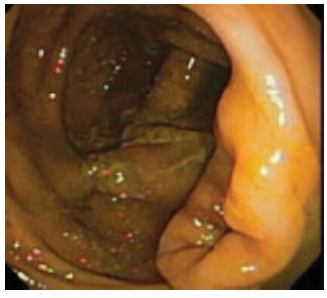

Fig. 7.25 The less common position of the ileocecal valve. The ileocecal valve is at 5 o'clock position.

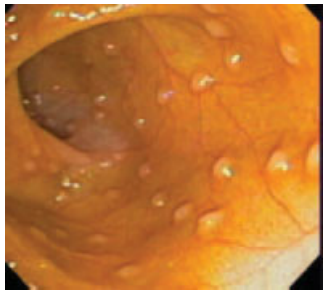

Fig. 7.26 The terminal ileum. Velvet texture, yellowish tinge, and lymphoid follicles are the main endoscopic characteristics of the mucosa of the terminal ileum in children.

folds more flat and easy to explore. It is useful for detection of small lesions such a sessile polyp.

COMPLICATIONS

Routine use of colonoscopy in children would be impossible without solid proof that the procedure is safe. It does not mean, however, that it is free from complications. This issue should be fully disclosed and explained to the parents or caretaker as a part of informed consent.

Complications associated with colonoscopy in children can be classified according to

1 a necessity for hospitalization and

2 an absence or presence of structural damage of the intestine and or adjacent organs (Table 7.4).

The incidence of minor complications is difficult to estimate. Most likely it is underreported. First, it is unlikely that all minor complications were and are going to be counted. Second, some complications are clinically silent: serosal tears and small mesenteric hematomas have been accidentally discovered during unrelated surgery soon after colonoscopy in adults.

The reported frequency of serious complications related to pediatric colonoscopy is about 0.2%, which is similar to the data from large-scale multicenter studies in adults. Perforation is a major complication associated with colonoscopy and it can occur due to four reasons:

- Excessive pressure created by advancing forward or forcefully withdrawing the shaft of a colonoscope
- A tip imbedded into the bowel wall
- Excessive air pressure
- Inappropriate technique of polypectomy, hemostasis, or balloon dilation of a benign stricture

	Minor complications: no need for hospitalization	**Major complications: requirement for hospitalization**
Structural damage of the intestine or adjacent organs	Small, nonobstructing mucosal or submucosal hematomas, small mucosal lacerations, petechiae	Perforation, bleeding requiring blood transfusion and endoscopic or surgical hemostasis, postpolypectomy syndrome
Absence of structural damage	Transient abdominal pain, bloating, abdominal distention resolving after passing gas, mild dehydration secondary to bowel preparation	Cardiovascular and respiratory distress, prolonged episode of hypoxia requiring resuscitation and/or endotracheal intubation

Table 7.4 Complications associated with pediatric colonoscopy.

Three types of perforations related to diagnostic colonoscopy have been described. Shaft-induced perforations are the result of big loop formation. It is usually larger than expected and located on the antimesenteric wall.

Tip perforations are smaller and typically occur when the "sliding by" technique is used inappropriately or a tip is trapped in wide diverticula or imbedded into mucosa when orientation is lost.

Excessive air pressure perforation has been documented primarily with strictures of the left colon. Attempts to bypass the narrowed area create intermittent obstruction of the colon, accumulation of air in the upstream colon, and increased hydrostatic pressure, which could reach a critical level of 81 mm Hg for the cecum. Hydrostatic pressure of 169 mm Hg is required to perforate of the sigmoid colon in adults. This could explain the fact that majority of air pressure related perforation has occurred in the cecum and even in the ileum after the so-called uneventful colonoscopy. Hydrostatic perforations have not been described in children.

Most large traumatic perforations are immediately obvious. One of the presenting symptoms could be sudden onset of irreducible abdominal distention, decreased resistance to insertion of a colonoscope, failure to insufflate the collapsed colon, visible organs of a peritoneal cavity, and severe and progressively increasing abdominal pain. Immediate discontinuation of the procedure and request for plain abdominal films are mandatory. Closed perforations are less dramatic. Almost 10% of patients with a perforated colon can be initially symptoms free. In addition, another 10–15% of patients may develop mild to moderate abdominal pain or discomfort. Absence of free are in the peritoneal cavity does not rule out perforation. High level of suspicion and careful postprocedure observation are clues for early recognition of complications. Persistent abdominal pain and/or low-grade fever should be considered a sign of perforation until proven otherwise. Early diagnosis in these circumstances is absolutely crucial to prevent or decrease morbidity and mortality associated with perforation of the colon. Treatment of colonic perforation can be nonoperative or surgical. Patients with a well-prepared colon and therefore decreased risk of significant contamination of the peritoneal cavity, absence of peritonitis, and otherwise stable can be treated medically with bowel rest, broad-spectrum antibiotics, and parenteral nutrition. Deterioration of a patient's condition, signs of peritoneal irritation, and suspicion of a large spillage of intestinal contents into the peritoneal cavity mandate a surgical exploration. According to large-scale studies in adults, the frequency of colonic perforation after polypectomy is usually higher by two or three fold. It results from excessive thermal coagulation of the tissue either due to inappropriate

setting of power and mode of current (more often when a "blended" mode is used), cutting the large sessile polyp more than 2 cm without a piece-meal technique or due to accidental contact of the adjacent mucosa with the head of a cut polyp. These perforations are often small and subtle and cause late onset of abdominal pain a few hours after the procedure. Severity of pain usually increases with time. Fever is another common sign of deep tissue necrosis. The treatment of these complications (polypectomy syndrome) is similar to uncomplicated diverticulitis, i.e., aggressive treatment with broad-spectrum antibiotics, bowel rest, and good hydration.

Bleeding after a diagnostic colonoscopy is quite rare and can be prevented by a thorough history and physical exam. History should be focused on a family history of bleeding diathesis, frequent nasal bleeding, oozing from gums after the brushing of teeth, and easy bruising without obvious trauma. A simple question about recent treatments with aspirin and/or nonsteroidal anti-inflammatory drugs is an effective way to prevent bleeding secondary to platelets dysfunction.

Bleeding disorders are not a contraindication to pediatric colonoscopy. Even patients with moderate to severe hemophilia could be undergoing successful colonoscopy with biopsy or polypectomy after special preparations conducted by pediatric hematologists. According to American Society for Gastrointestinal Endoscopy, colonoscopy and colonoscopic polypectomy are classified as a low risk for bacteremia. In recent publications, a transient bacteremia has been reported in less than 4% of patients after an uneventful colonoscopy. The patients usually remain asymptomatic without requiring any medical treatment. If patient becomes febrile, flat abdominal and cross-table films, blood culture, and empirical treatment with broad-spectrum antibiotics are mandatory. Malnourished, immunodeficient patients and children with congenital or acquired valve defects are at risk of infectious complications and endocarditis due to transient bacteremia. These children should receive antibiotics prior to colonoscopy. Careful observation in a recovery room (until the child is fully awake and ambulatory) and next day telephone follow-up should be a routine part of the postprocedure protocol.

COMMON PATHOLOGY

Rectal bleeding

Every child with hematochezia does not require colonoscopy. Careful history and physical examination are essential for diagnoses of bacterial, protozoal, or antibiotic-associated colitis, or an anal fissure. In the pediatric patients with persistent or recurrent hematochezia, and no identifiable cause, colonoscopy is

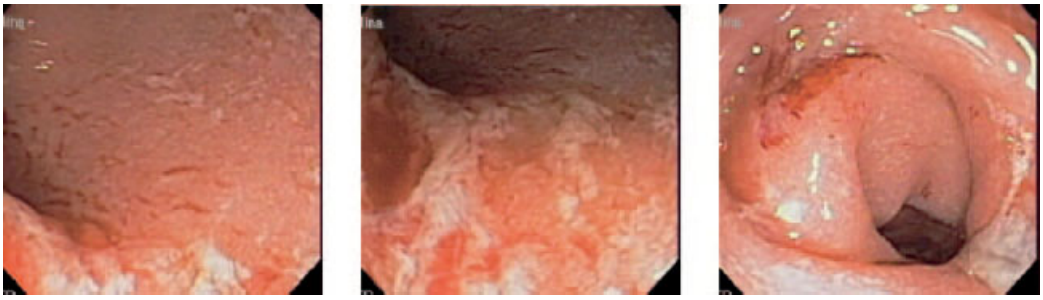

Fig. 7.27 Ulcerative colitis. Diffuse inflammation is typical for ulcerative colitis: erythema, exudates, loss of vascular pattern.

the procedure of choice to search for mucosal changes or other lesions associated with bleeding.

Ulcerative colitis is characterized by continuous and circumferential inflammation, diffuse erythema, edema, increased mucosal friability, disappearance of vascular pattern, granular appearance, grayish exudates, and microulcerations or shallow ulcer (Fig. 7.27). Ulcerative colitis typically begins in the rectum and spreads proximally. It may be mild or intense and may involve the rectum and the left or entire colon. "Cecal patch" of local inflammation surrounding the appendiceal orifice may coexist with left-sided colitis (Fig. 7.28). Signs of the so-called "back-washed" ileitis can be found in the terminal ileum: diffuse mild to moderate erythema, edema, and petechiae within 5–10 cm of the ileum adjacent to the ileocecal valve. Severe form of ulcerative colitis presents endoscopically with some degree of narrowing and tubular appearance of the bowel due to severe edema and loss of circular folds, striking erythema, large amount of pus, and shallow ulcerations (Fig. 7.29).

Deep ulcers are not typical for ulcerative colitis even with severe form of the disease. Chronic and relapsing course of ulcerative colitis leads to unequal distribution of inflammation, formation of pseudopolyps, and attenuation of vascular pattern (Fig. 7.30).

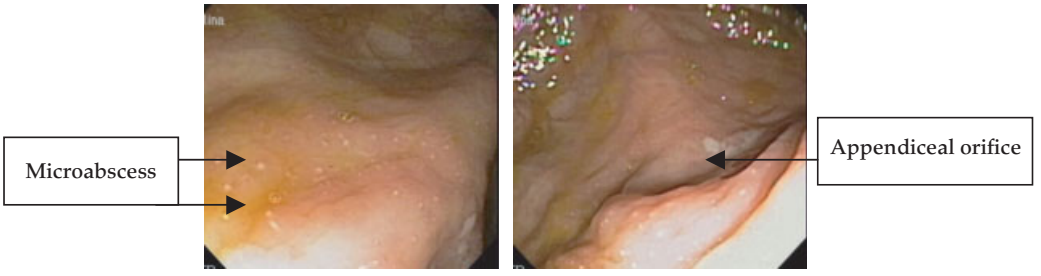

Fig. 7.28 Rare case of "cecal patch" in a child with left-sided ulcerative colitis. Left picture: multiple microabscess aroud the appendiceal orifice (close-up view); Right picture: appendiceal orifice.

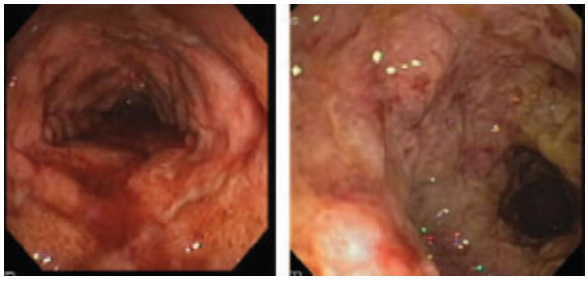

Fig. 7.29 Severe form of ulcerative colitis. Large amount of pus, severe edema, loss of vascular pattern, and small ulcerations are seen.

Colitis in patients with Crohn's disease is rather patchy than uniform. It could be mild or intense, and may involve all or just a part of the colon. Fifty percent of patients with Crohn's colitis have rectal sparing. At least half of children with Crohn's disease have ileocecal involvement. A so-called skip lesion is common. Aphthous ulcer is a common manifestation of Crohn's disease. It is a small 4–5-mm ulcer surrounded by a thin rim of erythema (Fig. 7.31).

Aphthous ulcers can be clustered in few colonic segments or spread throughout the colon. The other characteristic features of Crohn's disease are the signs of deep inflammation: narrowing of the lumen, strictures, mucosal bridging, and different kinds of ulcers such as stellate, longitudinal, tortuous, and serpiginous (Figs. 7.32–7.35).

The importance of the colonoscopy in patients with inflammatory bowel disease is to define the extent of inflammation, to obtain sample tissues to look at histologically to establish the specific diagnosis, and as an aid to planning therapy.

Allergic colitis is typically seen in infants. The endoscopic markers of this condition are hemorrhages, edema, and focal erythema of the rectum and the sigmoid colon (Fig. 7.36).

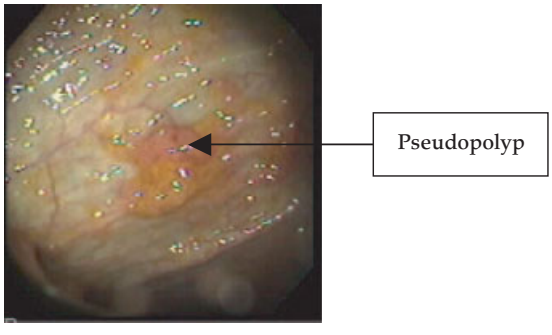

Fig. 7.30 Pseudopolyp in a patient with long-standing ulcerative colitis.

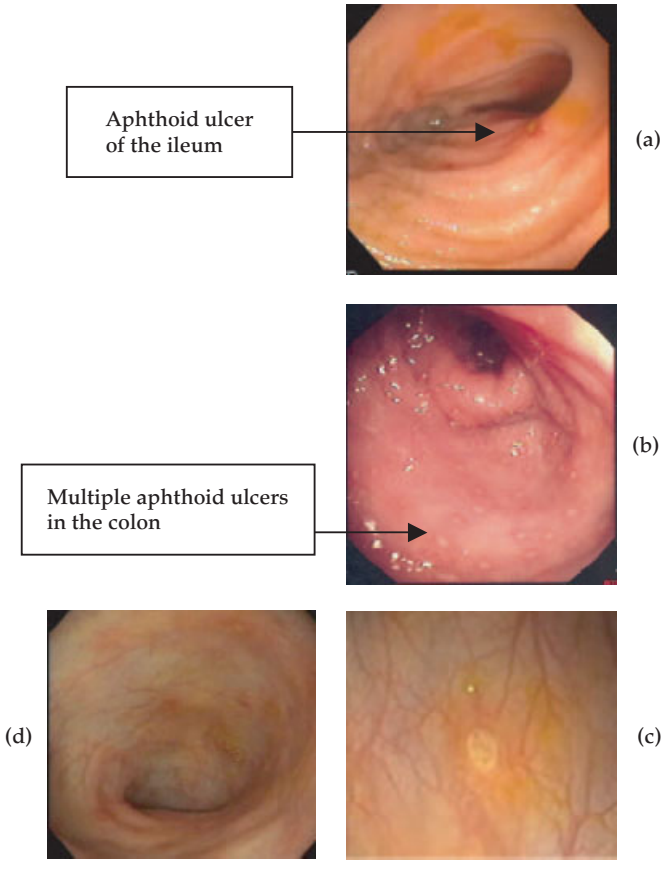

Fig. 7.31 Aphthoid ulcer. It is small, shallow lesion with the rim of erythema. (a) Aphthoid ulcer of the ileum; (b) multiple aphthoid ulcers in the colon; (c) multiple aphthoid ulcers in the colon; (d) a close-up view of the aphthoid ulcer.

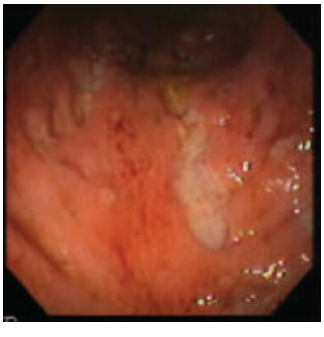

Fig. 7.32 Deep longitudinal ulcers in a patient with Crohn's disease.

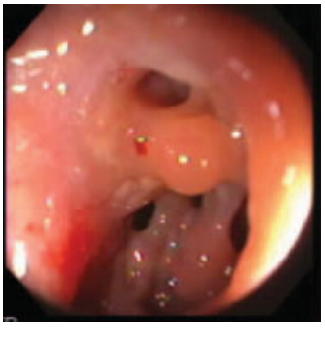

Fig. 7.33 Mucosal bridging in the cecum in 14-year-old patient with Crohn's disease.

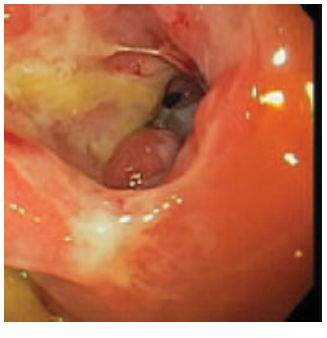

Fig. 7.34 Tight stricture and severe inflammation of the ileocecal area in a patient with Crohn's disease.

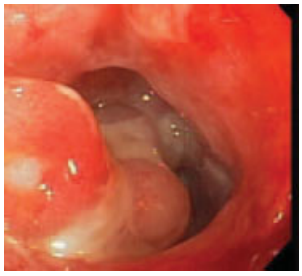

Fig. 7.35 Severe inflammation and large pseudopolyp in the ileocecal region in a patient with Crohn's disease.

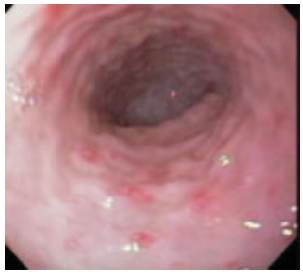

Fig. 7.36 Allergic colitis. Focal erythema, small aphthoid-like lesions, and edema of the sigmoid colon.

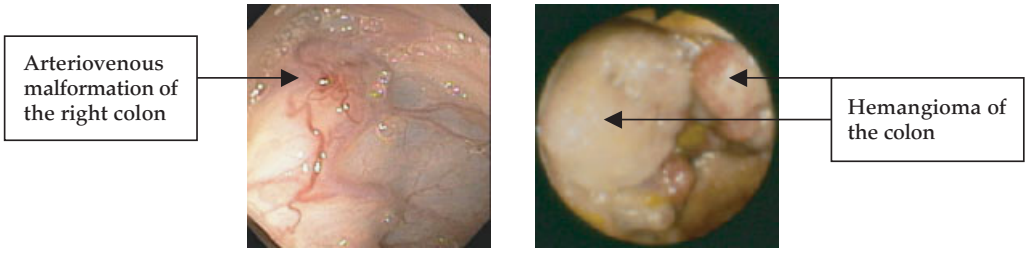

Fig. 7.37 Vascular lesions in the colon.

Rare lesions such as arteriovenous malformations or hemangiomas may be discovered (Fig. 7.37).

Isolated petechiae or small ulcerations in the rectum and the distal sigmoid colon could be results of bowel preparation (Fig. 7.38).

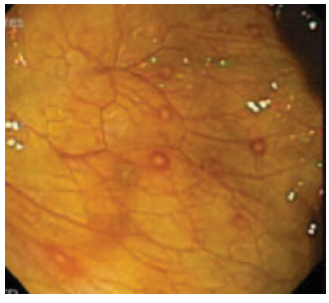

Fig. 7.38 Small aphthoid-like lesions can be occasionally induced by bowel preparation.

Polypoid lesions, polyps, and polyposis syndromes

Nodular lymphoid hyperplasia of the colon is typically seen in early infancy and is characterized by the umbilicated lesions in the rectum, sigmoid, and/or more proximal colon (Fig. 7.39).

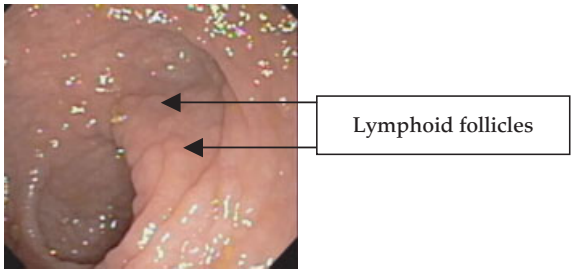

Fig. 7.39 Numerous lymphoid follicles in the sigmoid colon.

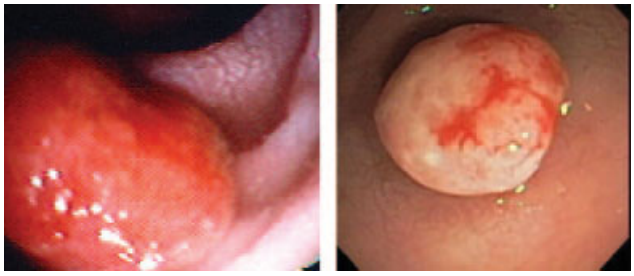

Fig. 7.40 Sessile juvenile polyp.

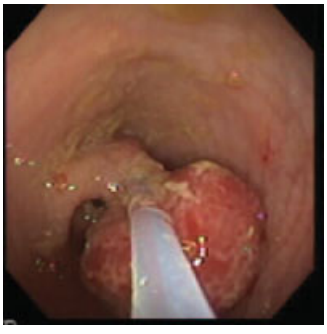

Fig. 7.41 Pedunculated juvenile polyp.

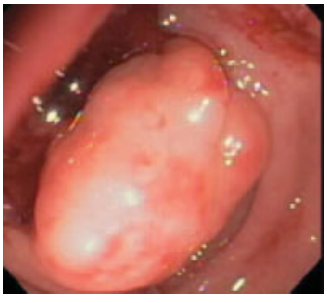

Fig. 7.42 Large juvenile polyp in the descending colon.

Juvenile or inflammatory polyps are not uncommon in children. They are most prevalent in the 4–6-year age group but may be present as early as in 1-year-olds. They are uncommon after age 18. Although autoamputation may occur in these cases, many will not spontaneously disappear.

The coexistence of juvenile polyps in the rectum, the sigmoid colon, and more proximal colon has been documented in at least third of children. For this reason a colonoscopy with polypectomy is the procedure of choice for children with recurrent painless rectal bleeding. A typical juvenile polyp is small (less than 1 cm) sessile or pedunculated structure. It has raspberry or smooth appeared "head" with or without a stalk (Figs. 7.40 and 7.41). A large juvenile polyp is usually located in the sigmoid colon. In rare cases it could be found in the descending and transverse colon (Fig. 7.42). Such a polyp may induce an intermittent pain due to colonic intussusception. The endoscopic marker of a nearby large juvenile polyp is the so-called goose skin sign (Fig. 7.43).

Different type of hereditary polyposis syndromes can be diagnosed during pediatric colonoscopy. Diagnostic criteria for juvenile polyposis are the presence of 3–5 or more juvenile polyps in

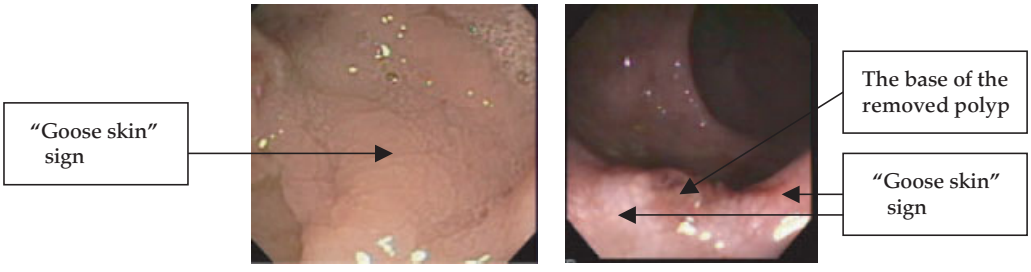

Fig. 7.43 The "goose skin" sign. The mucosa around a large juvenile polyp has specific pattern induced by lipid-loaded macrophages.

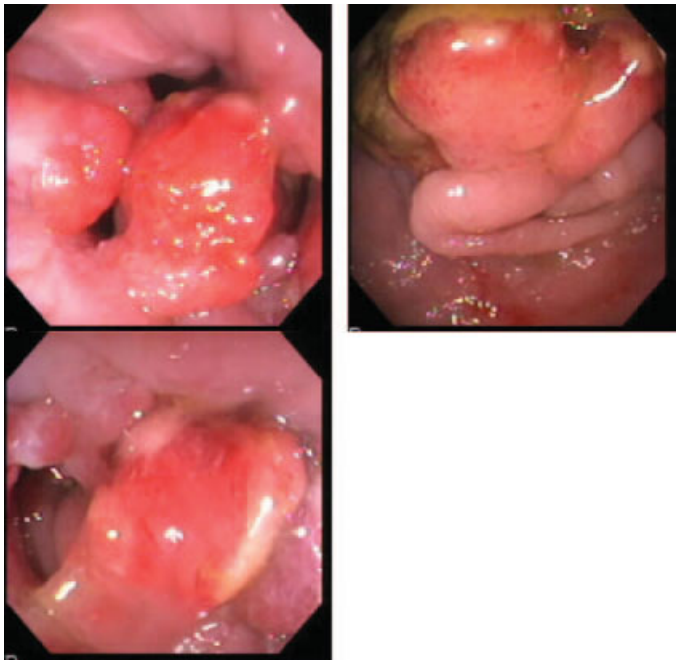

Fig. 7.44 Juvenile polyposis. Multiple juvenile polyps in the rectum and the colon.

the colon (Fig. 7.44). Surveillance colonoscopy is indicated due to increased risk of colon cancer.

Peutz-Jeghers's syndrome rarely presents with isolated colonic hamartomas. More often clusters of gastric, small bowel, and colonic polyps can be seen. The optimal diagnostic and therapeutic strategy consists of combined upper GI endoscopy, push enteroscopy, colonoscopy with polypectomy, and capsule endoscopy surveillance to prevent chronic intussusception and malignant transformation. Laparoscopy-assisted enteroscopy is the procedure of choice for treatment children with the small bowel hamartomas. A new method of a double balloon enteroscopy has not been validated in pediatric patients yet.

Colonoscopy has a leading role in diagnosis of familial polyposis coli, Gardner polyposis, and other forms of hereditary polyposis in children. It is also a tool for colorectal cancer surveillance in these patients. The colon may contain dozens or hundreds of usually small sessile polyps (Fig. 7.45).

Multiple biopsies and polypectomy of the largest polyps provide tissues for initial diagnosis of low- or high-grade dysplasia. Upper GI endoscopy should be performed in these patients, especially in children with Gardner's syndrome who care a high

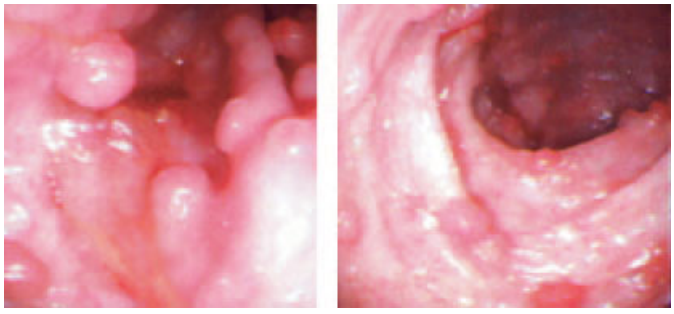

Fig. 7.45 Multiple colon polyps in 5-year-old boy with Gardner's syndrome.

risk of synchronous lesions in the gastric body and the second portion of the duodenum.

Asymptomatic children of patients with inherited polyposis syndromes should undergo a surveillance colonoscopy since 11 years of age. Once the patient is diagnosed with familial polyposis coli, a colectomy with ileal–anal pull-through procedure should be planned.

Chronic diarrhea

Chronic nonbloody diarrhea is an uncommon indication for colonoscopy; however, if the diarrhea has indeed been chronic in nature and the stool cultures and ova/parasites have been nondiagnostic, colonoscopy can help to establish a correct diagnosis. Microscopic colitis has been described in children presenting with chronic diarrhea, abdominal pain, loss of appetite, and weight loss.

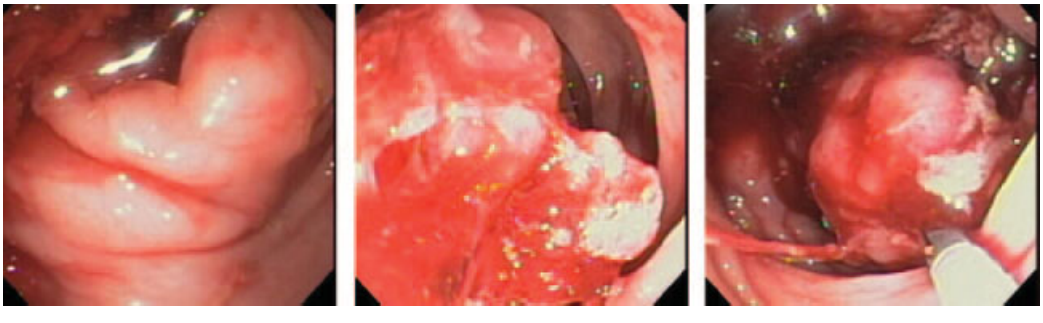

Fig. 7.46 Adenocarcinoma of the right colon in 11-year-old boy with significant weight loss, anemia, and ascites. Colonoscopy revealed severe edema of the distal part of the ascending colon. Further exploration of the ascending colon showed ulcerated large tumor. The biopsy confirmed the diagnosis of mucinous adenocarcinoma.

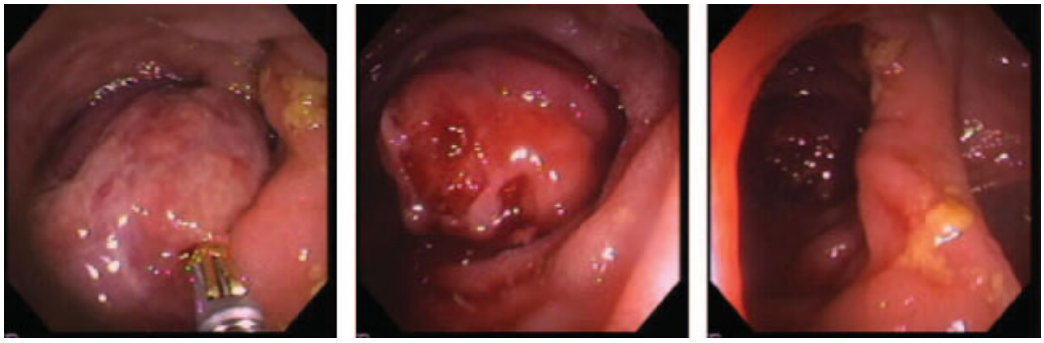

Fig. 7.47 Non-Hodgkin's lymphoma of the ileum. The indications for a colonoscopy were intermittent severe right low quadrant pain, weight loss, and anemia. The intussusception was found in the descending colon. It was gently reduced after the tissue samples were cautiously obtained.

Cancer surveillance

Development of adenocarcinoma of the colon in children is extremely rare but does occur even in children who never had ulcerative colitis. It typically presents with a progressive weight loss, fatigue, intermittent rectal bleeding, and anemia. Tumor is equally located in the left or right colon. It is quite difficult to identify an ulcerated mass due to almost complete obstruction and severe edema of the surrounding tissue. Usually the edge of the firm, easily fragmented during biopsy, discolored mass can be seen (Fig. 7.46). Non-Hodgkin's lymphoma of the ileum can be discovered during colonoscopy in children with intermittent abdominal pain and weight loss. Pain is a result of the ileocolonic intussusception; red irregular mass occupying the intestinal lumen could be found in ascending colon (Fig. 7.47). A biopsy cares a risk of pealing of a quite large fragment of tissue. Proper fixative solution is important for morphological and cytogenetic diagnosis.

Adenocarcinoma of the colon in ulcerative colitis

The determining factor in who develops cancer in ulcerative colitis seems to be the severity of the original disease as well as the extent of mucosal involvement and the duration of colitis.

The cancer risk for patients with pancolitis is 3% in the first decade of disease and 1–2% per year thereafter. Patients with universal colitis should begin biyearly colonoscopy, 10 years after onset of disease. Multiple biopsies within few cm intervals are recommended. Any flat or elevated lesions should be additional targets. Chromoendoscopy has been found useful to increase the yield of finding high-grade dysplasia in adults.

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Practical Pediatric Gastrointestinal Endoscopy
George Gershman, Marvin Ament

Polypectomy

8

BASIC PRINCIPLES OF ELECTROSURGERY

The cornerstone of electric cutting and coagulation of a living tissue is heating of the restricted area by radio frequency (RF) alternating current without stimulation of nerves and muscles. When current alternates up to a million times per second, it does not stimulate muscle and nerve membranes long enough to induce depolarization before the next alternation occurs. Cutting is produced by rapid and strong heating, which creates evaporation of intracellular and extracellular fluids.

Coagulation is initiated when the speed and degree of tissue heating is slower and less intense, leading to cellular desiccation. Specific effects of different types of RF currents and heat-related tissue destruction are illustrated in Figs. 8.1 and 8.2.

Several factors regulate the degree of tissue heating:

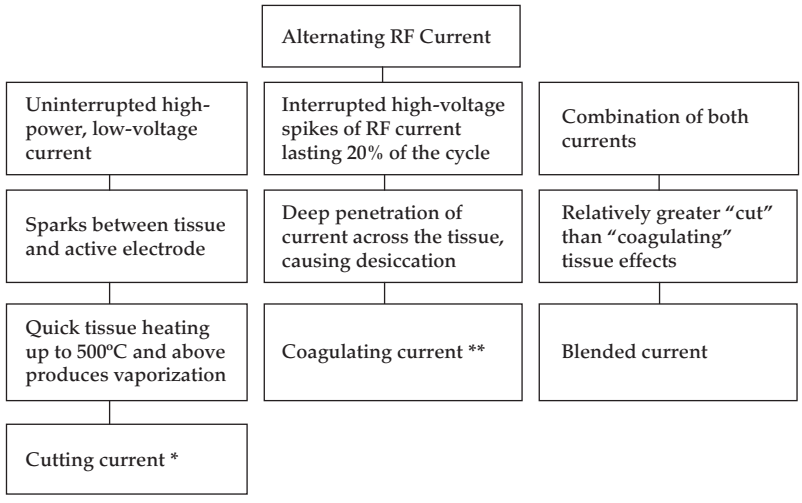
- Voltage (V) is the force required to push current through the tissue. The higher the voltage, the deeper the thermal tissue destruction.
- Tissue resistance (R) or impedance (for alternating current) is the force generated by the tissue to resist electric flow. It is directly proportional to the amount of tissue electrolytes.

  Resistance increases dramatically during tissue heating and desiccation. Normal tissue resistance is not uniform; it is the lowest along the blood vessels and the highest at the level of the skin.
- Time (T) is an essential factor of energy (E) regulation, which can be expressed as

$$E(\text{in joules}) = P(\text{power in watts}) \times T$$

Tissue heating increases with time, although the process is quite complex:

- Heating produces water losses and increases resistance
- Increasing resistance shifts the distribution of current from the lowest resistance pathway
- Fluctuation of resistance affects the power output produced by the generator
- Some of the released heat is removed from high-temperature areas by blood flow. The cooling effect of blood flow explains why the same energy applied to the tissue generates less destruction, if delivered slowly.



* Low-voltage current penetrates less through desiccation tissue and has limited ability to induce deep tissue heating.

** Spikes of high-voltage coagulating current allow a deeper spread through desiccated tissue and induce more tissue destruction.

Fig. 8.1 Different types of alternating RF currents and specific tissue response.

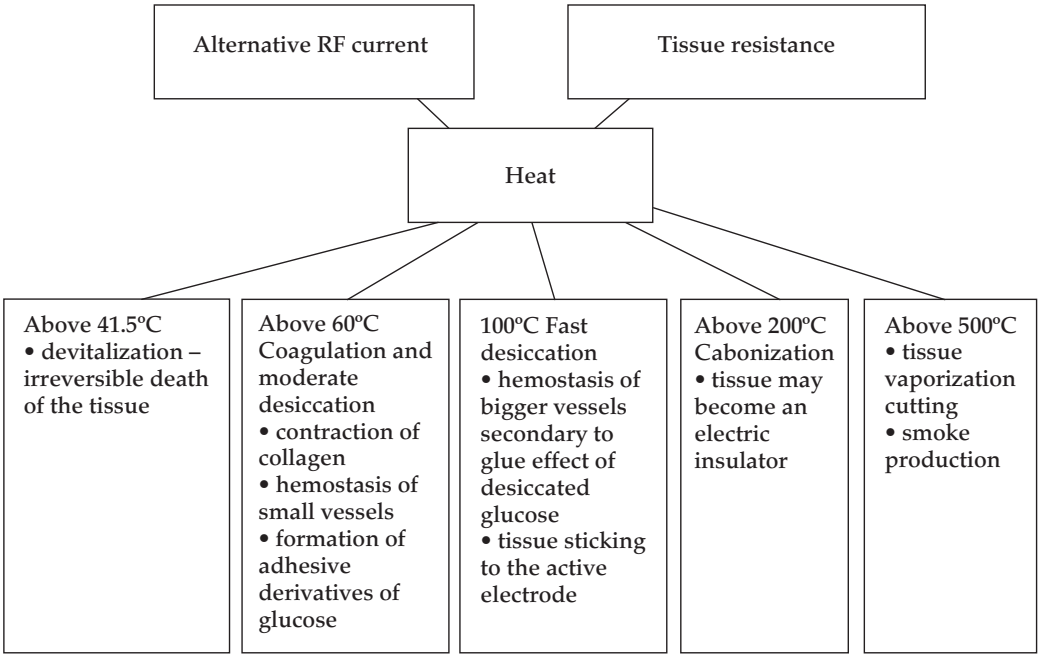


Fig. 8.2 Temperature-related tissue destruction always induced by RF current.

- Current density is a measure of RF current (I) that flows through a specific cross-sectional area (a):

$$\frac{I}{a} = \frac{I}{\pi r^2}$$

The amount of heat generated in the tissue is directly proportional to power density (P), expressed as a square value of current density multiplied by resistance:

$$P = \left(\frac{I}{a}\right)^2 \Re = \frac{I^2}{\pi r^2} \times \Re$$

This important equation implies that power density is in inverted relationship with the square of the cross-sectional area (πr^2). It means that even small tightening of the wire loop produces a profound effect on tissue heating. This can be illustrated by polypectomy of a 1-cm polyp.

If a snare decreases the diameter of a polyp in half, the cross-sectional area at the level of the loop will be only 0.2 cm^2. It is 4 times less than the cross-sectional area at the basis of a polyp and about 500 times less than that of skin under a 10 × 10 cm plate of the "return" electrode.

If 0.2 A electric current is applied through the snare, it produces a current density of 1, 0.25, and 0.002 A/cm^2 at the level of the loop, polyp basis, and skin level, respectively. The fall of power density, i.e., power actually delivered to the tissue and generated heat, is even more dramatic: from $1A/cm^2 \times R$ at the level of the loop to 0.06 $A/cm^2 \times R$ and 0.000004 $A/cm^2 \times R$ at the basis of the polyp and skin under the return electrode, respectively. Narrowing of a cross-sectional area by a closing snare produces the most significant effect on heat production compared with increasing power setting and time of electric current application. It also allows one to perform a polypectomy at a low power, using a coagulating mode safely.

The law of current density is vital for polypectomy. Narrowing of a cross-sectional area is the most important safety technique, which produces a coagulation of core vessels of the polyps before cutting, restricts the area of maximal tissue heating around the loop, and limits tissue destruction of the deep bowel wall layers.

SNARE LOOPS

Commercially available snares vary by size, configuration of the loop, design and mechanical characteristics of the handles and, wire thickness. Reusable snares often loose their mechanical properties and can peel and break at the tip. Disposable snares are more durable and predictable. The thickness of the wire loop and handle "behavior" can significantly affect the

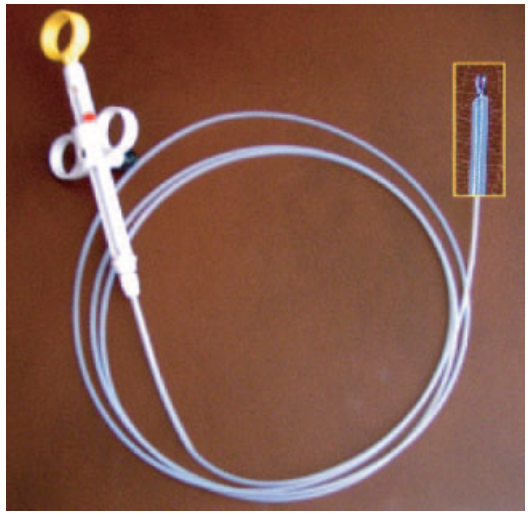


Fig. 8.3 Snare preparation before polypectomy: marking of so-called closing point on the handle of the snare.

results of polypectomy. Snares with thick wire loops have two important advantages:

- Decreased risk of snapping a polyp without adequate coagulation
- Large surface contact with tissue and better coagulation.

A standard snare with an opening diameter of 2.5 cm can be used for different size polyps. A special small or "mini" snare (1-cm loop) has been designed for polyps less than 1 cm. It is important for endoscopists to find an "optimal" snare for routine practice in order to avoid unexpected "surprises" during cutting or coagulation.

A chosen snare should be fully open and then closed to the point when just the tip of a wire loop is outside of outer sheath. Marking of the so-called closing point on the handle of the snare (Fig. 8.3) serves two important safety features:

- Protects from premature cutting of a small sessile or pedunculated polyp without an adequate coagulation
- Alerts the endoscopist to partial polyp's head entrapment or underestimation of the stalk size.

It is very important to check how far the tip of a wire loop is retracted into the outer plastic sheath when a snare is fully closed. The distance of 15 mm reassures an adequate squeezing pressure (Fig. 8.4). If the stalk of a large polyp is not squeezed adequately, it compromises the coagulation of core vessels by two reasons:

- Blood vessels remain open and blood flow continues producing a cooling effect but, more importantly,

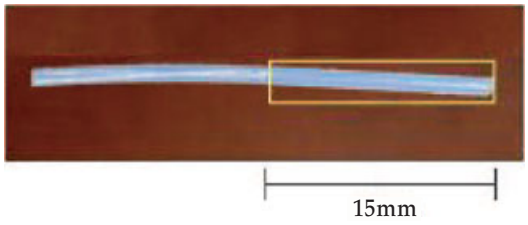


Fig. 8.4 Squeezing pressure. A fifteen mm retraction of the wire into the plastic sheath provide an optimal narrowing of the polyp base or the stalk for adequate constriction of the blood vessels and generation of an appropriate power density.

- a cross-sectional area is not narrow enough to concentrate the current flow to an appropriate power density to coagulate the core vessels.

Closure of a snare loop with excessive pressure can induce premature cutting before coagulation. Both conditions could lead to significant bleeding.

POLYPECTOMY ROUTINE

Polypectomy is the most common therapeutic procedure in pediatric gastrointestinal endoscopy. It can be simple or more complex depending on the size or location of the polyp and personal experience. No matter how easy the polyp appears to the endoscopist, it is always wise to follow a simple rule: safety before action.

SAFETY ROUTINE

It is always useful to routinely inspect the snare and generator as well as to prepare hemostatic equipment such as detachable loops, metal clips, and needle for epinephrine injection. The polypectomy snare should be checked for smooth opening, thickness of the wire (a thin snare predisposes to a premature cut of a small polyp before appropriate coagulation), adequate squeezing pressure, and closing point. It is extremely important to test a generator to find a minimal power setting, which is necessary to induce whitening and swelling of the tissue inside a wire loop. It should be done at least once by adjusting the power output according to the effect of short (2–3 s) burst of coagulating current until a visible effect is achieved. The generator setting should be inspected routinely before the procedure to avoid an accidentally high power setting. A foot pedal should be conveniently positioned in front of the endoscopist. A teaching session with an assistant or a technician is important for safe and optimal manipulations with a snare during opening or closure.

SAFETY CONDITIONS AND TECHNIQUES

A good bowel preparation is essential not only for optimal view and positioning of the loop around a polyp stalk or base, but also to avoid an accidental burning or coagulation of normal mucosa. A large amount of liquid or solid stool increases the chance of missing a small and even a good size polyp. An obscure view often leads to excessive use of air and bowel stretching, which makes the bowel wall thinner.

Sudden patient irritability, unexpected awaking, or movements complicate polypectomy especially during a snare closure and should be prevented by adequate sedation.

The technique of polypectomy consists of three important elements:

1 Navigation of the scope to an optimal position, angle, and distance to a polyp
2 Placement of a wire loop around a polyp
3 Cutting.

A 6 o'clock position is an ideal one for polypectomy. A location of a polyp between 4 and 5 o'clock and 7 and 8 o'clock is suboptimal. Polypectomy is very difficult and somewhat unsafe if a polyp is located on the upper aspect of a lumen between 9 and 3 o'clock.

An ideal 6 o'clock position could be created by clock- or counterclockwise rotation of the shaft and downward deflection of the tip. Careful assessment of stalk size and location of a polyp is obligatory before polypectomy. It can be done by rotation, advancement of a scope beyond a polyp, and pulling the shaft backward. Once an optimal position and clear view of a polyp is achieved, the scope is moved toward the polyp base. An ideal distance form the tip of the scope to a polyp is 1–2 cm unless a polyp is hiding beyond a fold. In this case the tip of the closed snare should be positioned just above the fold and pressed down to reveal the polyp. The same effect can be achieved by manipulations with the use of a closed snare.

All manipulations with a snare should be slowly done. It is opened just enough to embrace a polyp. Full opening of a snare makes the wire less controllable.

Snaring a sessile polyp at 6 o'clock position is easy if the wire loop is horizontal to the polyp. Simple downward tip deflection is needed to move a loop and encircle a polyp. If an opened wire loop creates an angle to the base of a polyp, the shaft of the scope should be rotated toward the polyp until it is caught. The technique is modified if a sessile polyp is located between 4 and 5 o'clock or 7 and 8 o'clock and attempts to establish an ideal 6 o'clock position have failed. The shaft is slightly rotated away from a polyp. The snare is opened more than usual to make it less rigid and slide toward the polyp (Fig. 8.5). Once the polyp is

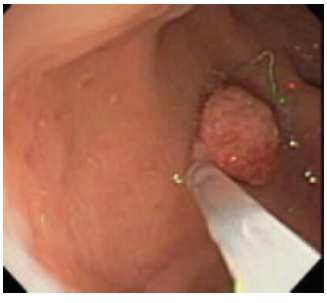


Fig. 8.5 The snare is placed around the polyp.

inside the loop, the scope is rotated slowly toward the polyp to align the plane of a snare with the axis of a bowel lumen. Then the snare is closed slowly and moved forward until it reaches the base of the polyp. At this moment the snare should be completely closed (Fig. 8.6).

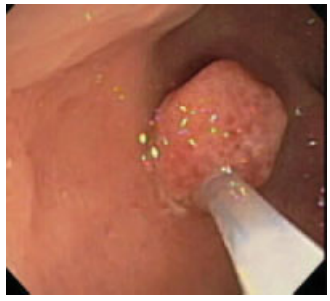


Fig. 8.6 The snare is closed tight but not enough to amputate the polyp.

Occasionally, a backward snaring is more effective, especially if the polyp is more than 1.5 cm in length. An open loop is pointed down to the area where a polyp head touches the bowel wall. When the snare is advanced, tissue resistance creates a bowing effect and induces a loop opening. As a result, the loop slides between the mucosa and the polyp head. An additional clockwise rotation of the tip using both knobs swings a wire loop under the polyp head. If the position of the snare is satisfactory, the snare is slowly closed tight enough for polypectomy.

If a polyp is facing away from the tip, the snare is advanced and opened slowly until the tip of the wire is beyond the polyp's head. The tip of the scope is deflected down slightly to move the wire loop below the polyp. After that the snare is pulled back until the head of the polyp is inside the loop and the wire is just under the polyp head. The snare is closed slowly and advanced toward to the polyp to prevent sliding of the wire along the stalk.

Advancement of the snare toward the polyp during wire loop closure is a key element to polyp snaring. It secures a polyp within the loop and allows precise navigation of the snare. The capturing of a small polyp with a standard snare may be challenging. A slight decompression of the bowel may elevate a polyp above a wire loop and facilitate a capture.

The technique of polypectomy is different when applied to small polyps less than 5 mm, broad-based polyps more than 15 mm, or pedunculated polyps more than 20 mm. Diminutive or small sessile polyps less than 5 mm can be removed safely by cold biopsy forceps. Two helpful hints are as follows:

1 If a polyp is located on the edge of a fold, position the tip of the colonoscope within a distance of 2 cm from the polyp, open the forceps and place the open cusps perpendicular to the fold just above the polyp, and close it. Avoid pushing the forceps up against the mucosa as it will stretch the tissue and result in suboptimal sampling.

2 If a small polyp is between the folds, try to position the snare with cusps opened horizontally and just enough to outline the polyp. Advance the forceps forward slightly to cover the polyp and close the forceps slowly. An alternative technique consists of

- opening the forceps with cusps vertical to the folds,
- positioning the lower cusp just below the polyp to avoid grasping normal mucosa, and
- closing a forceps.

A large sessile polyp is rare in children except in patients with Peutz-Jegher's syndrome. Polyps more than 2.5–3 cm are usually located in the small intestine, primarily in the jejunum. If the size of a polyp is between 10 and 15 mm, a single-cut polypectomy may be safe if advancement of a snare with captured polyp does not produce synchronous movements of the underlying wall. This indicates that submucosa and muscularis propria are not trapped within the wire loop.

Piece-meal technique: Piece-meal technique is used for piece-by-piece removal of a large broad-based polyp, more than 15 mm. A submucosal injection of saline, hypertonic saline, or epinephrine (1:10,000) solution before polypectomy decreases the risk of the transmural burns.

Injection at site proximal on the polyp is performed first if possible, followed by injections at the distal edge and both sides of a polyp. Injection of 3–10 cc of a chosen solution at three to four sites is usually adequate to create a liquid "cushion" under the polyp. The needle should be oriented tangentially to minimize the risk of transmural injection.

Once again, a broad-based polyp more than 15 mm should be removed in pieces to minimize the risk of perforation. The risk of bleeding is not high since blood vessels in such polyps are much smaller than in large pedunculated polyps.

The piece-meal technique consists of placement of a wire loop diagonally across a polyp and removing the polyp in few pieces. The remaining central area is cut at the end. Excessive closing pressure should be avoided because it may compromise initiation of cutting due to lack of electric arc from the active electrode to the tissue. In addition, decreased wire–tissue contact area increases current density, which may induce excessive desiccation and cease current flow.

Polypectomy of pedunculated polyps more than 2 cm may be challenging. Attention should be paid to proper positioning of the wire loop at the narrowest portion of a stalk right below a polyp head. Thick blood vessels in the middle of a stalk require slow desiccation for complete coagulation and hemostasis before the final cut. Endo-loop® and clipping devices should be available for immediate action. It is quite difficult to avoid direct contact of a large pedunculated polyp with normal mucosa during polypectomy. However, attempts should be made to keep a snared polyp close to the center of the bowel lumen to minimize thermal destruction of adjacent tissue. Careful inspection of a long stalk should precede any manipulations with a snare. The location of the polyp base and position of the long stalk are crucial for optimal approach to the polyp. The snare is advanced forward to the lowest point of the polyp head and opened slowly until the loop is big enough to embrace the polyp.

Further manipulation with the snare should be coordinated with either right or left torque of the shaft toward the 6 o'clock direction. Backward snaring may be useful. The reduction of a polyp size by piece-meal technique with prior injection of epinephrine solution (1:10,000) into a stalk below the polypectomy site is the last option to complete the procedure.

After successful capture and adequate tightening of the wire loop, a polyp less than 10 mm is removed by using a low-power coagulating current (15–18 W) continuously for 2–3 seconds and by slow closure of a snare after whitening and tissue swelling has occurred. A modified technique is applied to sessile polyps less than 15 mm or large pedunculated polyps with a small pseudo stalk. Injection of saline or epinephrine (1:10,000) solution underneath the polyp head protects deep tissue from desiccation and decreases mobility of the polyp, which simplifies a placement of the wire loop without trapping a part of the polyp head. A slightly longer duration of coagulation (2–3 cycles) may be necessary for adequate coagulation of blood vessels.

A blended current up to 20–25 W may be reasonable for polypectomy of a broad-based polyp, using a piece-meal technique.

Different electrosurgical generators have different setting systems: a dial type system with a scale from 0 to 10. Usually, a setting point between 2.5 and 3 are equivalent to a low power of 15–20 W; a numeric-type system, when displayed, numbers represent current power in watts.

An endoscopist should become familiar with the particular electrosurgical generator available for his or her practice to avoid an application of excessively high power above 30 W, which could lead to a transmural tissue necrosis.

A polypectomy can be performed during colonic intubation or withdrawal phase of colonoscopy. The decision is made based on the size of the polyp. It is wise to remove a small sessile or pedunculated polyp as soon as it was discovered to eliminate the chance of missing this polyp later on. Removal of a large polyp is more convenient after the entire colon has been inspected except in the case when the position of a polyp is ideal for polypectomy. Careful examination of the colon (especially behind the folds) can be accomplished by circumferential rotation of the tip and the shaft, aspiration of excessive fluid, and repeat insertion of the scope for a few segments if the bowel quickly slipped away from the tip.

After polypectomy, polyps less than 10 mm can be easily sucked into a biopsy channel and eventually into a filtered polyp suction trap. Water irrigation and proper orientation of a suction nostril at the tip of a scope facilitate the recovery process.

During polypectomy, attention should be paid to remove polyps and to observe the direction where it falls. The first place

to look for a hidden polyp is in a pool of fluid. If a polyp is not discovered, flush some water and watch where it flows: backflow indicates that the polyp is distal to the tip of the scope.

Nylon polyp retrieval nets or metal baskets can be used for removal of multiple polyps. Grasping of a large polyp by the snare is the most reliable way to bring it to the rectum. Manual assistance in the recovery of a specimen may be necessary to squeeze a large polyp more than 3 cm through the anus.

COMPLICATIONS

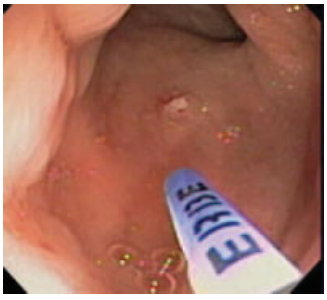


Fig. 8.7 APC is useful tool of hemostasis. Bleeding after polypectomy was successfully controlled by argon plasma probe.

Three types of complications can occur after polypectomy. The most common one is bleeding. In contrast to adults, a delayed bleeding within 2 weeks after the procedure is quite rare. Immediate onset of bleeding is more common, although the incidence of this complication is less than 1% in infants and children. This may reflect a smaller size, the number of polyps, and the absence of comorbid conditions such as hypertension and atherosclerosis. A slow oozing from the polpypectomy site is easy to control by injection of epinephrine solution (1:10,000) or by bipolar or argon plasma coagulation (Fig. 8.7).

The risk of arterial bleeding always exists right after polypectomy of a large pedunculated polyp due to incomplete coagulation of thick vessels. Endoscopic hemostasis should be prompt before a large amount of blood and clots make the bleeding vessel invisible. A temporary hemostasis can be achieved almost immediately by resnare and tightening of the stalk. After a few minutes, the wire loop should be replaced by the Endo-loop® for permanent hemostasis. In addition, injection of epinephrine below the Endo-loop® can augment a hemostatic effect.

FURTHER READING

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Practical Pediatric Gastrointestinal Endoscopy
George Gershman, Marvin Ament

Chromoendoscopy

9

Chromoendoscopy is the topical application of dyes to the gut mucosa, carried out in order to allow or improve the endoscopic localization and characterization of a specific tissue or lesion. Generally, the identification of a lesion can be accomplished either by a positive or negative staining; i.e., the dye either stains the lesion or the normal mucosa surrounding it. Chromoendoscopy can be used in combination with optical enhancement (magnification endoscopy) to further increase the yield of biopsy particularly in case of suspect dysplasia or cancer. Although it was developed and first used some 30 years ago, chromoendoscopy is seldom used in everyday clinical practice for a number of reasons. Apart from highlighting mucosal lesions that have to be biopsied or removed, the superiority of chromoendoscopy on standard endoscopy and histology has not been demonstrated yet. The recognition and interpretation of lesions imply a degree of subjectivity and the procedure requires some extra time. Fortunately, dysplasia and cancer are an uncommon occurrence in the gastrointestinal (GI) tract of infants and children, and thus their recognition is not such a relevant issue as in adult gastroenterology. On the other hand, chromoendoscopy techniques are simple, quick, inexpensive, and generally safe and the equipment needed is widely available. Furthermore, in large pediatric GI referral centers, conditions where endoscopic surveillance for the detection of dysplasia are indicated – such as Barrett's esophagus, early onset inflammatory bowel disease (IBD), or familial polyposis syndromes – may well be seen. Finally, the recent development of therapeutic endoscopic technologies such as mucosal resection and photodynamic therapy, which require a precise tissue localization and characterization, have produced a renewed interest in chromoendoscopy worldwide.

INDICATIONS

Esophageal disorders

One potential indication of chromoendoscopy in the pediatric esophagus is intestinal metaplasia, i.e., Barrett's esophagus. If this condition is suspected, the main aim of chromoendoscopy is to help increase the diagnostic yield of endoscopic biopsies. Positive staining with methylene blue could also be used to identify

endoscopically invisible intestinal metaplasia of the cardia region, which may exist in patients with gastroesophageal reflux disease (GERD). However, it is questionable if methylene blue staining should be applied to all patients with long-standing GERD who undergo upper endoscopy, because intestinal metaplasia can also be found in asymptomatic individuals and the advantage of methylene blue staining over random biopsy is controversial. In adult patients with short-segment Barrett's esophagus, the sensitivity of methylene blue staining for the detection of intestinal metaplasia varies from 60 to 98% but is generally higher than that of random biopsies. Abnormal methylene blue staining can also be helpful in delineating dysplastic or malignant areas for endoscopic treatment such as mucosal resection or photodynamic therapy. If mucosectomy is planned, a minimum amount of methylene blue injected with saline into the underlying submucosa will stain it blue, thereby facilitating an accurate removal of the mucosal lesion. In patients who have undergone mucosal ablation, chromoendoscopy could also help distinguish the regenerating squamous epithelium from residual Barrett's mucosa. Lugol's solution has also been used in follow-up endoscopic examination of young patients who have been treated for Barrett's esophagus or dysplasia, in order to promptly detect remnants of unstained Barrett's epithelium.

Studies in adults have shown that chromoendoscopy with Lugol's solution is superior to conventional endoscopy for the detection of severe dysplasia and early squamous cell carcinoma of the esophagus. In a Chinese population with high esophageal cancer rate, chromoendoscopy with Lugol's solution showed a sensitivity of 62–96% and a specificity of 63%. However, esophageal dysplasia and cancer are extremely uncommon in pediatric patients, and it should be kept in mind that Lugol's solution can also stain an inflamed esophageal mucosa, namely, reflux esophagitis. Other staining techniques such as indigo carmine and acetic acid have been proposed in association with magnification endoscopy to detect Barrett's esophagus and dysplasia. Staining with toluidine blue has been reported to have a very high (98%) sensitivity for Barrett's esophagus, but cannot distinguish between gastric and intestinal metaplasia.

Although studies in adults have shown promising results, so far there are insufficient data supporting a routine use of chromoendoscopy for detecting Barrett's esophagus and dysplasia in children.

Helicobacter pylori infection and related disorders

To date, there are no clear-cut indications for the use of chromoendoscopy to detect specific gastric disorders in clinical practice.

At least two reactive dyes, however, deserve attention and may prove useful in the near future. Congo red stains acid-secreting mucosa and has been used in adult patients to detect gastric atrophy, which appears as an area of negative staining on the dark blue/black background of the normal mucosa of the gastric fundus and body. Phenol red turns from yellow to red in the presence of alkaline pH, such as that related to the hydrolysis of urea by urease-producing *H. pylori*, and has been used to map the extent of *H. pylori* colonization in the stomach. Both these staining techniques could therefore find an application in pediatric patients with long-standing or refractory *H. pylori* infection.

Celiac disease

Gluten-sensitive enteropathy (celiac disease) usually results in endoscopically visible changes of the duodenal mucosa, including a "mosaic" pattern, loss or indentation (scalloping) of Kerckring's folds, and a visible vascular pattern. Chromoendoscopy with methylene blue emphasizes the mosaic pattern, though it does not seem to increase the diagnostic yield of endoscopy, at least when performed by experienced gastroenterologists. In one study, indigo carmine scattering combined with magnification endoscopy proved superior to standard endoscopy for the detection of small bowel enteropathy, mainly because it was able to distinguish between total and partial villous atrophy. However, since the diagnosis of celiac disease is established by histology and not by endoscopy, duodenal biopsies should be taken whenever celiac disease is suspected, irrespective of the endoscopic appearance of the duodenal mucosa. Therefore, the major contribution of chromoendoscopy in celiac disease is to allow for better targeting – and consequently some sparing – of duodenal biopsies.

Polyposis syndromes

Chromoendoscopy may be very useful to detect smaller lesions in the duodenum of patients with familial adenomatous polyposis (FAP). Small flat duodenal adenomas may in fact go unnoticed during standard endoscopy and even capsule endoscopy, but can be identified as negative-staining lesions when an absorptive dye such as methylene blue is sprayed onto the mucosa. In *colonic polyposis*, the main aim of chromoendoscopy is the same as in the duodenum, i.e., to increase the detection rate by facilitating the identification of small flat polyps, especially adenomas. The preferred dye for the detection of colonic polyps is indigo carmine, a contrast stain that pools in areas of mucosal irregularity and often gives a three-dimensional effect, which is particularly useful for the detection of small protruding lesions.

Needless to say, magnification endoscopy and high-resolution endoscopy can add to the accuracy of the technique. In adult studies, left-sided or total colonic indigo carmine staining significantly increased the detection rate of small flat or depressed adenomas. Chromoendoscopy can also help distinguish between hyperplastic and adenomatous polyps, as they produce different staining patterns. In a recent multicenter study, more than 90% of colonic polyps were correctly classified according to the staining pattern, and for adenomatous polyposis the sensitivity and specificity were 82% and the negative predictive value was 88%.

Inflammatory bowel disease

In IBD, the greatest potential for chromoendoscopy is the ability to early detect dysplasia or cancer in patients with long-standing ulcerative colitis. Colonic dysplasia and colitis-related colon cancer may occasionally be a problem also in pediatric patients, as in case of ulcerative colitis presenting before 10 years of age, especially if associated with sclerosing cholangitis. In a randomized controlled trial on 174 patients with long-standing ulcerative colitis, total colonic methylene blue staining was clearly superior to conventional surveillance endoscopy with biopsy for the detection of early neoplasia (32 vs 10 overall intraepithelial lesions; 24 vs 8 low-grade; and 24 vs 10 in flat mucosa).

Other indications

In the duodenal bulb, methylene blue spray can help identify areas of gastric metaplasia, which is a marker of inflammation such as that related to *H. pylori* infection. Methylene blue was also used to identify the minor papilla in patients with pancreas divisum.

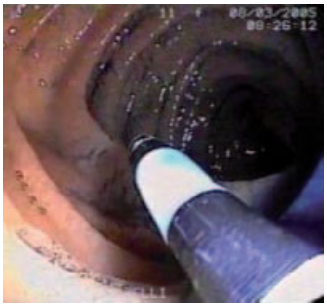


Fig. 9.1 The tip of a pediatric ERCP catheter pushed through the biopsy channel is seen in the distal duodenum, prior to dye spraying.

APPLICATION TECHNIQUE

Equipment

Special reusable spray catheters such as those used for endoscopic retrograde cholangiopancreatography (ERCP) (e.g., Olympus PW-5L1) are preferable. The biopsy channels of all modern pediatric videoendoscopes allow the passage of such catheters (Fig. 9.1). It is also convenient to use a new biopsy channel cap in order to minimize the leakage of dye. Endoscopists and support staff with less experience in chromoendoscopy should be particularly careful, as most dyes can produce a fairly persistent staining of skin and clothing. Depending on the specific indication and need, different type of stains can be used, i.e.,

Dye (%)	Staining mechanism	Color	Main clinical application(s)
Methylene blue (0.5%)	Absorption into intestinal epithelial cells	Blue	Intestinal metaplasia in esophagus (Barrett's) Intestinal metaplasia in stomach Gastric metaplasia in duodenum (*negative staining*) Celiac disease
Lugol's solution (1–5%)	Binding to glycogen-containing cells	Dark green/ brown or black	Squamous esophageal cancer (*negative staining*) Residual postablation Barrett's (*negative staining*) Esophagitis (*negative staining*)
Toluidine blue (1%) Indigo carmine (0.1–0.5%)	Binding to nuclear DNA of malignant cells Pools in mucosal crevices and pits	Blue Indigo (blue/violet)	Squamous esophageal cancer Small, flat, or superficial polyps Barrett's esophagus Dysplasia or cancer in ulcerative colitis
Congo red (0.3–0.5%)	Stains acid-producing mucosa (pH <3)	Turns red to dark blue/black	Mapping of acid-secreting mucosa Gastric cancer, gastric atrophy, and intestinal metaplasia (*negative staining*)
Phenol red (0.1%)	Stains alkalinized mucosa	Turns yellow to red	Mapping of *H. pylori*-infected mucosa Gastric metaplasia (*negative staining*)
India ink (1%)	Staining of mucosa at site of injection	Black (permanent)	Site of endoscopically removed polyp Lesion to be removed surgically

Table 9.1 Types of staining.

stains that are absorbed by the mucosa (vital stains), stains that produce contrast (reactive stains), and stains for tattooing of the mucosa (Table 9.1).

Methylene blue

Methylene blue is actively absorbed by the intestinal epithelium and does not stain nonabsorptive tissues such as the normal esophageal or gastric mucosa. Optimal staining requires

washing of the mucosa with a mucolytic agent such as N-acetylcysteine prior to spraying a 0.25–0.5% solution of the dye and subsequent washing with water. The absorptive intestinal epithelium – including metaplastic epithelium as in Barrett's esophagus – is stained blue, whereas the nonabsorptive epithelium – such as ectopic gastric metaplasia – is delineated as an area of negative staining against a blue-stained background. The presence of dysplasia or early malignancy within Barrett's epithelium result in inhomogeneous staining as a consequence of the differential absorption of methylene blue from cells that are depleted of goblet cells and have less cytoplasm. Methylene blue is generally considered to be safe. However, it has been reported that, once photosensitized by white light, methylene blue may induce oxidative damage of the DNA and although it does not usually stain the dysplastic intestinal epithelium, there is concern that it may increase the risk of carcinogenesis in patients with Barrett's esophagus. The parents of patients in whom methylene blue staining is being used should be warned that their child's urine and stool might temporarily acquire a green-bluish color.

Lugol's solution

Lugol's solution contains iodine, which has a special affinity for the glycogen contained in squamous epithelia. For this reason it is most commonly used in the esophagus, where the normal squamous epithelium is stained green/brown to dark brown or black. Malignancy, dysplasia, metaplasia, or even simple inflammation is associated with glycogen depletion and the affected mucosa will thus appear as an unstained area on a dark stained background. Severe allergic reactions to iodine have been reported, so allergy to iodine should be carefully excluded in patients who are undergoing chromoendoscopy with Lugol's solution.

Toluidine blue

Toluidine blue is a basic dye that binds to the nuclear DNA of epithelial cells, and therefore can be used to identify tissues with an increased DNA synthesis such as malignancy. Toluidine blue staining has been mainly used in the endoscopic screening for malignant gastric ulcers and early squamous esophageal cancers in at-risk populations, e.g., heavy alcohol drinkers and smokers.

Indigo carmine

Indigo carmine is the most widely used contrast stain and is especially useful to identify and define the margins of neoplastic

lesions. Indigo carmine, in fact, typically pools in areas of mucosal irregularity, which are stained indigo (blue/violet) color. After washing, pits, grooves, and edges of the lesion are highlighted and this may produce a three-dimensional effect, which is particularly useful for the detection of small superficial lesions. Indigo carmine at a concentration of 0.1–0.5% is usually sprayed onto the gut mucosa, but may also be given orally in a capsule. Although mostly utilized to identify small superficial polyps, indigo carmine has been applied in several other conditions such as Barrett's esophagus, gastric cancer, sprue, and ulcerative colitis.

Congo red

Congo red reacts to an acidic pH by changing from red to dark blue/black. Its major application is the identification and mapping of nonsecretory gastric mucosa such as that of gastric atrophy, intestinal metaplasia, and gastric cancer, which will appear red in contrast to blue/black secretory areas. A stimulation of acid production with pentagastrin is therefore necessary before staining.

Phenol red

Phenol red is also a reactive dye, but unlike Congo red it reacts to an alkaline pH by changing from yellow to red. Patients should undergo pretreatment with a proton pump inhibitor and an anticholinergic, plus the local application of a mucolytic. Once 0.1% phenol red and 5% urea have been sprayed onto the gastric mucosa of *H. pylori*-infected individuals, the alkalinized mucosa is stained red, whereas areas of intestinal metaplasia in the stomach will stain negative.

Acetic acid

Acetic acid is a newcomer to GI chromoendoscopy. Preliminary studies suggest that acetic acid stain may help identify Barrett's esophagus as well as duodenal atrophy in celiac disease by delineating the features of the metaplastic or atrophic intestinal epithelium.

India ink

When injected into the mucosa, 1% india ink produces a permanent black staining. India ink can be injected superficially into the mucosa to mark the site where a worrisome polyp has been

endoscopically removed, or it can be injected deeper to mark a lesion that has to be removed surgically.

Patient's sedation

Because the main aim of chromoendoscopy is to allow for the visualization of small and fine features of the gut mucosa, the whole procedure can be rendered completely useless if the patient is restless or agitated. Therefore, unless the patient is fully cooperative – which is the exception rather than the rule in pediatric endoscopy – an adequate sedation is mandatory to maintain the patient still throughout the procedure. Conscious sedation with midazolam 0.05–0.20 mg/kg intravenous (IV) may not be sufficient in infants or very anxious children, where deep sedation with propofol or a brief general anesthesia may be necessary.

Preparation of the mucosa

There is no doubt that chromoendoscopy gives better results when the gut mucosa to be examined is cleared from mucus (and blood, bile, or food debris; if present). So, whenever possible, the mucosa should be washed prior to staining. A better washing is obtained if forceful pressure is applied with a syringe either through the spray catheter or directly into the biopsy channel. If absorptive dyes such as methylene blue or Lugol's solution are to be used, the mucosa should be washed with a few milliliters of 10% N-acetylcysteine to adequately remove mucus. Once the tissue has been stained, a wash with water or saline can remove the excess, nonabsorbed dye. If the vision is disturbed by bubbles or foam, a small volume of antifoam preparation (e.g., simethicone, 10–20 drops) can be added to the wash. A spasmolytic drug such as hyoscine N-butylbromide can be administered IV to reduce peristalsis or smooth muscle spasm and maximize visualization of the mucosal area of interest. As mentioned above, when a pH-sensitive dye is used, acid secretion should be either stimulated or suppressed, depending on the dye being used.

Staining technique

The technique for staining is fairly simple. Once the gut area of interest has been reached and adequately washed (see above), the endoscope and the tip of the catheter should be directed toward the mucosa with a combination of clockwise and counterclockwise rotation movements, and the dye should be sprayed onto the mucosa while the tip of the endoscope is gently and slowly withdrawn. The only exception is india ink staining, which is in fact a permanent tattoo of the mucosa and as such requires

1 *S*trict patient selection: patients with histologically proven ulcerative colitis and at least 8 years' duration in clinical remission; avoid patients with active disease
2 *U*nmask the mucosal surface: excellent bowel preparation; remove mucus and remaining fluid in the colon when necessary
3 *R*educe peristaltic waves: when drawing back the endoscope, a spasmolytic agent should be used if necessary
4 *F*ull-length staining of the colon: in ulcerative colitis, perform panchromoendoscopy rather than local staining
5 *A*ugmented detection with dyes: vital staining with 0.4% indigo carmine or 0.1% methylene blue should be used to unmask flat lesions more frequently than with conventional colonoscopy
6 *C*rypt architecture analysis: using magnification endoscopy all lesions should be analyzed according to the pit pattern classification; whereas pit pattern types I–II suggest the presence of nonmalignant lesions, staining patterns III–IV suggest the presence of intraepithelial neoplasias and carcinomas
7 *E*ndoscopic targeted biopsies: perform targeted biopsies of all mucosal alterations, particularly of circumscribed lesions with staining patterns indicative of intraepithelial neoplasias and carcinomas, i.e., pit patterns III–IV

From: Kiesslich and Neurath 2004.

Table 9.2 "SURFACE" guidelines for chromoendoscopy in ulcerative colitis.

injection into the mucosa or submucosa. Once satisfactory images are obtained, it is always advisable to take photographs of the stained mucosa, in order to compare staining features with the histological abnormalities, to assess interobserver variability and also to monitor the improvement of the staining technique overtime. Recently, guidelines have been proposed for optimal chromoendoscopy in ulcerative colitis (Table 9.2), but most of these guidelines do apply to chromoendoscopy in general.

RECOGNITION OF THE LESIONS

Barrett's esophagus and related disorders

Methylene blue is absorbed by the intestinal epithelium, so it has been used for the endoscopic detection of the intestinal metaplasia typical of Barrett's esophagus, especially when the diagnosis is uncertain as it may be in short-segment Barrett's. The staining is usually homogeneous, but in short-segment Barrett's it may be somewhat patchy due to the presence of nonintestinal columnar cells. More importantly, in Barrett's esophagus the pattern of methylene blue staining is irregular and heterogeneous if dysplasia or cancer is present (Fig. 9.2). Heterogeneously stained or light blue/unstained areas should be biopsied with particular care in search of high-grade dysplasia and early adenocarcinoma. If Lugol's solution is used, Barrett's epithelium, dysplasia, or carcinoma will appear as areas of negative staining on the dark green/brown stained background of the normal squamous epithelium.

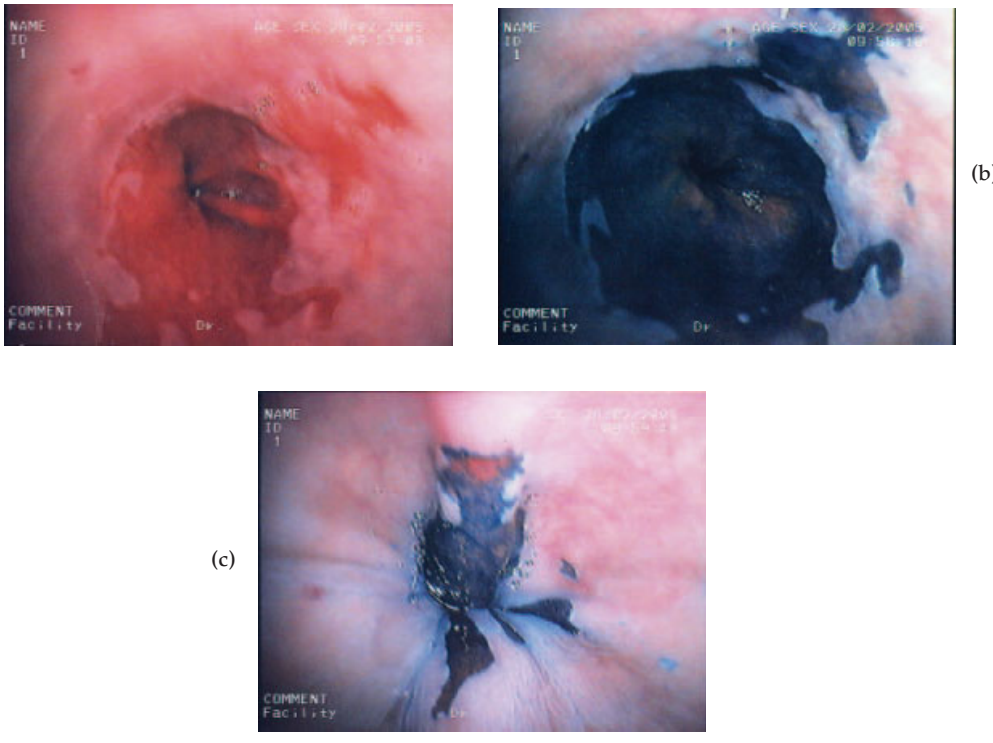


Fig. 9.2 Endoscopic view of Barrett's esophagus: (a) plain close view; (b) close view after 0.1% methylene blue staining; (c) with the endoscope slightly withdrawn, a small area of negative staining can be seen in the uppermost part of the lesion (top); biopsy of this area showed moderate-grade dysplasia.

H. pylori infection and related disorders

In patients with long-lasting *H. pylori* infection, chromoendoscopy with Congo red will demonstrate gastric atrophy as an area of negative staining on the dark blue/black background of the normal mucosa of the gastric fundus and body. Chromoendoscopy with phenol red will define the extent of *H. pylori* colonization in the stomach by producing a yellow staining throughout the affected gastric mucosa, which is alkalinized by urease.

Celiac disease

Staining with methylene blue, even without preparation of the duodenal mucosa, makes the typical mosaic pattern more prominent and crisp, emphasizing the coarse, "cobblestone" appearance of the celiac mucosa that may not be evident at standard endoscopy (Fig. 9.3). Immersion chromoendoscopy – i.e., 1% methylene blue spray combined with magnification obtained by

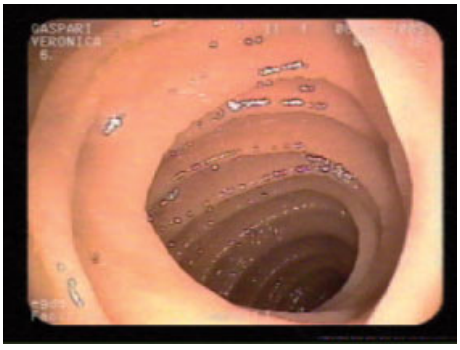
(a)   (b)

Fig. 9.3 Endoscopic view of the distal duodenum in a patient with celiac disease and total villous atrophy. (a) A very mild scalloping of Kerckring's folds can be seen, but there is no clear evidence of mucosal atrophy; (b) even without preparation of the mucosa, the mosaic pattern typical of gluten-sensitive enteropathy is clearly seen following methylene blue spray.

immersion of the endoscope tip – can amplify the difference between the mosaic pattern due to villous atrophy and the normal duodenal mucosa where villi can be clearly seen along the duodenal folds (Fig. 9.4).

Polyposis syndromes

In patients with FAP, small flat duodenal adenomas will be easily identified as negative-staining plaques following methylene blue spray (Fig. 9.5). In colonic polyposis, indigo carmine staining can help identify small superficial lesions such as flat or

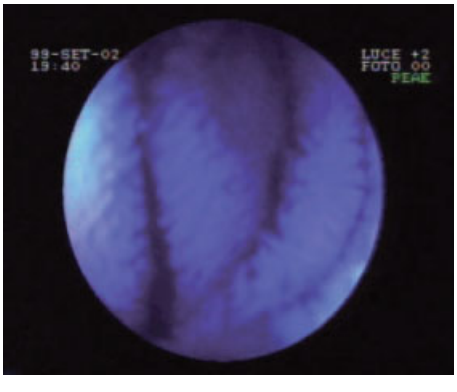
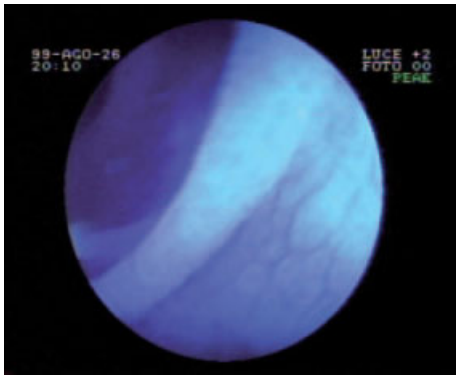
(a)   (b)

Fig. 9.4 Immersion chromoendoscopy after methylene blue spray, without preparation of the mucosa. Unlike the normal duodenum, where villi are clearly seen along the mucosal folds (a), in patients with celiac disease and total villous atrophy duodenal folds appear flat and "denudated" and the typical cobblestone or mosaic pattern of the mucosa is highlighted (b).

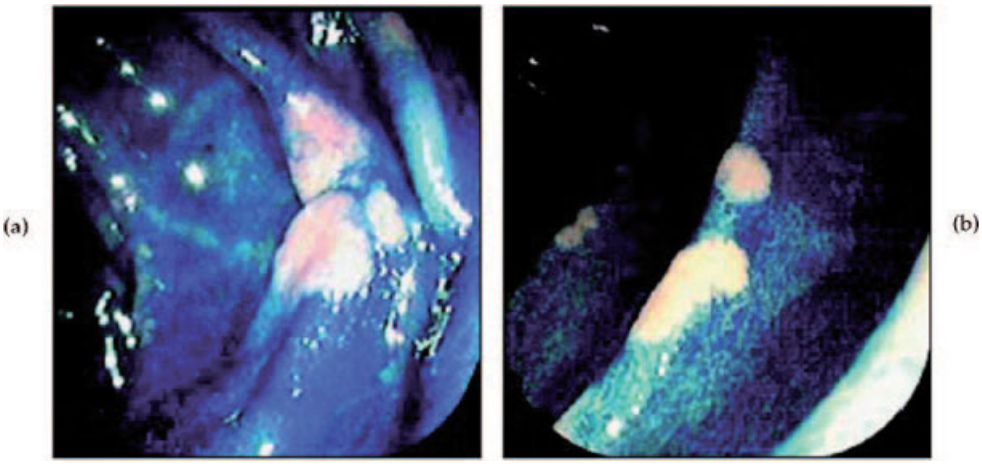


Fig. 9.5 In a patient with FAP coli, flat (a) or minimally raised (b) duodenal adenomas stand out as small areas of negative staining following methylene blue spray. (From: Weinstein 2005).

depressed adenomas. Indigo carmine and methylene blue can also differentiate hyperplastic (i.e., nonneoplastic) polyps from adenomatous (i.e., neoplastic) polyps, as the former are characterized by a regular pitted pattern (Fig. 9.6a), whereas a grooved or sulcus pattern is typical of adenomatous polyps (Fig. 9.6b).

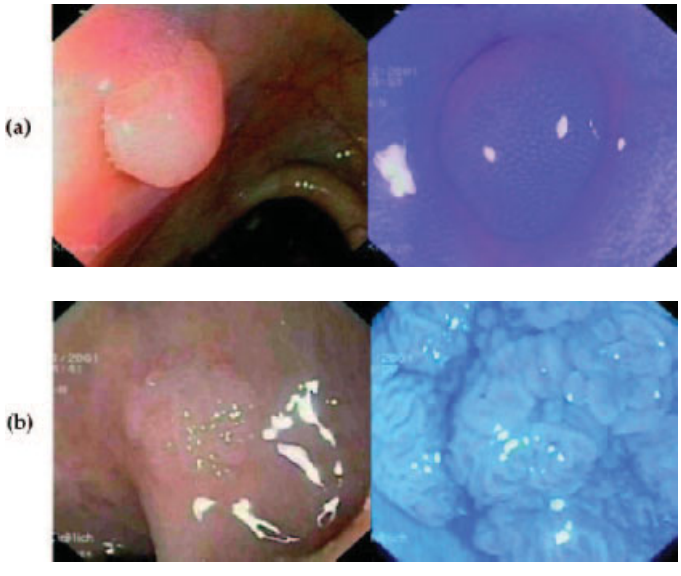


Fig. 9.6 Colonic polyps before and after chromoendoscopy: (a) hyperplastic polyp showing a regular pitted pattern and (b) neoplastic polyp showing a sulciform pattern. (From: Kiesslich and Neurath 2004).

Inflammatory bowel disease

In patients with long-standing ulcerative colitis, colonic dysplasia will appear as an area of negative-staining following methylene blue spray. If an early cancer is present within a metaplastic area, the staining will appear inhomogeneous and subsequent carmine red staining could be helpful to outline the margins of the lesion. As in colonic polyposis syndromes, methylene blue and indigo carmine staining can help discriminate between hyperplastic and neoplastic lesions (Fig. 9.6).

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Practical Pediatric Gastrointestinal Endoscopy
George Gershman, Marvin Ament

10 Wireless Capsule Endoscopy

HISTORY

An ingestible capsule was developed in 1957. Capsules were initially developed to measure gastrointestinal (GI) pH, temperature, and pressure. Thirty-seven years later Dr Gavriel Iddan, a senior engineer for the electro-optical design section of the Israel Ministry of Defense, submitted the first of a number of patents for a wireless capsule used to directly image the small intestine. To further development of the technique he collaborated with Dr Gabriel Meron to form GIVEN (gastrointestinal video endoscopy) Imaging Ltd. in 1998.

Dr Paul Swain from England had a similar idea for wireless endoscopy and demonstrated the concept at the World Congresses of Gastroenterology in Los Angeles in 1994. In 1996 he and his team published the first live transmission of wireless endoscopy images from the stomach of a pig. A complete study was published in *Endoscopy* in 2000. He used a miniature charge-coupled device camera, a microwave transmitter, and halogen and small torch bulbs wrapped in post mortem gastric tissue to demonstrate the feasibility of transgastric transmission to a color monitor. This was ultimately proven to be feasible in a human volunteer.

In 1998 Dr Swain joined GIVEN and with the technological development of complementary metal oxide silicon image sensors, application-specific integrated circuits devices, and white-light-emitting diode illumination, a working prototype of the M2A (mouth-to-anus) capsule was produced. The early version capsule was 11 × 30 mm with a 6-hour recorder.

THE GIVEN M2A SYSTEM

The GIVEN diagnostic imaging system is currently the only Food and Drug Administration (FDA) approved wireless endoscopy system. In 2003 it was approved as a first line modality for evaluation of small bowel disorders.

The GIVEN system consists of three main components: the M2A capsule, the sensor array antenna system with an attached data recorder, and the Reporting and Processing of Images and Data (RAPID) workstation to download and view the images.

The current M2A capsule is used only once. It weighs 3.7 g and measures 11 × 26 mm in size. The capsule consists of eight main

regions and is made up of biocompatible material, resistant to low gastric pH and other digestive fluids.

Patients fast overnight and take any necessary medications 2 hours prior to the ingestion of the capsule. The capsule takes two images per second and over 50,000 are taken during an average 8-hour study. Images are shown in 1:8 magnifications with a 140° field of view and a 1–30-mm depth of view. Objects as small as 0.1 m in size can be detected. To prevent obscuring the images, patients are asked to abstain from drinking fluids or consuming foods until 2 and 4 hours, respectively, after ingestion of the capsule. The images obtained by the capsule are transmitted to the eight sensors attached to the abdomen and stored in the data recorder worn around the patient's waist.

The data recorder requires five nickel-metal 1.2 V batteries and houses a 305 GB hard drive. The eight sensors are attached to the abdominal wall in a predetermined pattern to better estimate capsule location by means of a triangulation method of localization. The contents of the data recorder are downloaded into the RAPID workstation. The download usually takes less than an hour. The GIVEN proprietary software must be used to view the images. Images may be viewed as one image (single view) or two images (multiview) simultaneously. The adjustable rapid scan mode allows the viewer to view 1–25 images per second in the single view format and up to 40 images per second in multiview.

Landmarks in the stomach, the duodenal bulb, the cecum, and unidentified abnormalities may be marked by forming a thumbnail image. Depending on the speed of the rapid scan, average time of interpretation ranges from 30 to 90 minutes. Average gastric transit time in patients has been reported to be 47–69 minutes, and average small bowel transit time 210–314 minutes. Failure to reach the cecum during the recording period occurs in 27–53% of patients. The capsule is then excreted within 24–48 hours.

LOCALIZATION

Accurate localization of pathology in the small intestine may be difficult because of the free intraperitoneal location of the small bowel and its constant peristalsis. Because wireless endoscopy is entirely diagnostic, surgical intervention may be necessary for specific findings. The triangulation method of localization of the wireless capsule endoscope was initially introduced in 2001. The transmitted signal of the capsule is received by eight sensors attached to the patient's abdomen. Its location is estimated by three sensors at any given time: the sensor in closest proximity to the capsule receives the strongest signal, and two adjacent sensors that the capsule is located between will receive signals of nearly equivalent strength. Using the strength of the signals

and the location of the sensors an approximate location can be calculated.

This method of triangulation detected the capsule within 6 cm of its location in the abdomen, 87% of the time in healthy volunteers who also received fluoroscopy. The method allows the lesion to be roughly placed into a specific abdominal quadrant, but does not indicate the actual distance down the small bowel. Patients with small bowel lesions requiring surgical interventions may still require the use of intraoperative enteroscopy to precisely localize the lesion.

SUSPECTED BLOOD INDICATOR

A recent advance in this system has been the development of a suspected blood indicator (SBI). The SBI is a color detector designed to flag images containing the color red and marks these images for closer review. If actively bleeding lesions are evaluated, the system is quite excellent. Its sensitivity, positive predictive value, and accuracy increased to 81.2, 81.3, and 83.3%, respectively. If lesions are not actively bleeding, the overall sensitivity, positive predictive value, and accuracy for detecting small bowel lesions is 25.7, 90, and 34.8%, respectively.

INDICATION FOR USE

The M2A GIVEN capsule is FDA approved for evaluation of all suspected small bowel diseases. The most common indications for its use include patients with obscure GI bleeding and patients with suspected small bowel Crohn's disease. It may be used to detect small bowel polyps in patients with hereditary polyposis syndromes or in those with an abnormality on small bowel radiographic studies, and possibly in those with chronic abdominal pain.

DIAGNOSTIC YIELD

When capsule endoscopy was compared to push enteroscopy in a canine study using radiopaque colored beads sewn into the small bowel of nine dogs, the sensitivity and specificity of push enteroscopy for detecting beads implanted within the entire small bowel was 37 and 97%, respectively, compared to 64 and 92% for capsule endoscopy. The higher sensitivity for capsule endoscopy may be attributed to the larger number of beads found in the distal small intestine, out of the reach of the push enteroscope.

In studies in adults, comparing capsule endoscopy to push enteroscopy, the diagnostic yield of capsule endoscopy was 66% compared to 28% for push enteroscopy in the same patient

population. The most common sources of GI bleeding included vascular lesions, small bowel malignancies, and small bowel ulcerations. There have been multiple publications and abstracts supporting the use of capsule endoscopy in the evaluation of obscure GI bleeding.

Capsule endoscopy's role in evaluation of patients with Crohn's disease in whom there are no demonstrable lesions in the stomach or small intestine by upper gastrointestinal and small bowel series is unclear.

The role of capsule endoscopy for nonspecific or poorly localized pain is even less clear in Crohn's disease. The yield in a number of studies has varied from 4 to 54%. This discrepancy is most likely due to the heterogeneity of this patient population. More studies need to be done to clarify capsule endoscopy's role.

The use of capsule endoscopy and its diagnostic success in the small intestine should not replace a carefully performed upper endoscopic examination. Recent attempts have been made to improve the visualization of the esophagus and Z-line by having the patient in a lying down position for swallowing the capsule, allowing for a longer time to visualize the esophagus, and by using a camera in the capsule which takes more pictures in a given time period.

CONTRAINDICATIONS TO CAPSULE ENDOSCOPY

Absolute contraindications include GI obstruction and GI pseudo-obstruction, and ileus. Some relative contraindications include a history of a GI motility disorder such as gastroparesis, a history of intestinal strictures or fistula, pregnancy, presence of cardiac pacemaker or defibrillator, a known history of multiple small bowel diverticulum, a history of extensive abdominal surgeries or radiation, and an active swallowing disorder or dysphagia.

PACEMAKER SAFETY

The general consensus is to perform an electrocardiogram while placing an activated capsule next to the pacemaker device. If no abnormalities occur, the procedure may be continued.

BOWEL PREPARATION

There is no current recommendation for a bowel preparation in patients receiving a capsule study. No studies have definitely shown superiority of a bowel preparation compared to fasting.

PROMOTILITY AGENTS

Several studies presented in abstract form suggest that the use of erythromycin prior to and even during the study may lead to a higher percentage of complete examinations. One study in adults found that by using 200 mg oral dose of erythromycin 1 hour prior to capsule ingestion decreased emptying time by 65% and only 4% of cases failed to reach the colon compared to 21% in the control group. The mean small bowel emptying time did not change.

ENDOSCOPIC ASSISTANCE

Patients with esophageal narrowing or gastroparesis may need endoscopic assistance to insert the capsule into the small bowel. The methods include using a polypectomy snare in an unsedated patient undergoing endoscopy, a Roth Net in a consciously sedated pediatric patient, and a standard endoscopy to get the capsule out of the stomach.

Diagnostic yield depends on reader's experience, multiviewing images, and speed of review no faster than 15 frames per second (fps). Even at 15 fps, 21% of lesions were missed by experienced readers.

COMPLICATIONS

The major complication of capsule endoscopy is capsule retention. This is reported in 0.1–3.5% of cases. The capsule is often retained in a region of stricturing or within a diverticulum. Rarely, symptomatic small bowel obstruction has been reported. Individual patients with a prior history of abdominal surgery do not have a higher incidence of capsule retention.

OUTCOME OF CAPSULE ENDOSCOPY

This is still controversial. However, in patients with obscure GI bleeding who require multiple hospitalizations and chronic transfusions, a 10% benefit in outcome may be quite significant.

PEDIATRIC PATIENTS

There are limited studies in pediatric patients because of fewer ones with obscure causes of GI bleeding and because of the difficulty of swallowing the capsule in pre-school-age children. In children older than age 6, the capsule procedure was well tolerated; with only one pediatric patient it remained in the bowel for 10 days and was naturally excreted after corticosteroids were prescribed.

Indications and contraindications are the same in children as in adults.

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