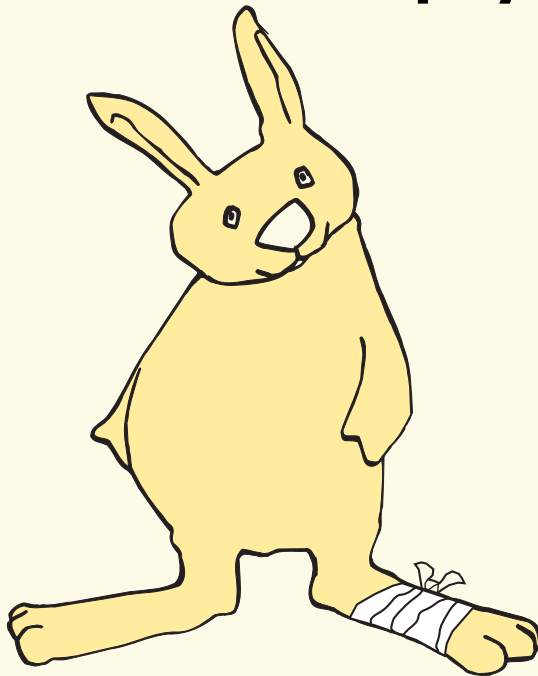


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V a d e m e c u m

Pediatric Laparoscopy



Thom E Lobe

v a d e m e c u m

Pediatric Laparoscopy

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VADEMECUM
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Dedication

To all who see the light.

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Preface

Since we compiled our first book on pediatric laparoscopy a decade ago, a lot has changed. In the early days, few pediatric surgeons challenged the establishment as they forged ahead, pushing the edges of the envelope before them, into a new area. We had to prove that pediatric laparoscopy offered some benefit to our patients. We had to justify every so-called “new” approach.

While some of us, as pioneers, paved the way and ignored the criticism of our colleagues, most chose to watch with interest. Over the ensuing years, pediatric laparoscopy made the transition from a novelty, the “look what I can do” phase, through the collecting of large experiences, to validation of the laparoscopic approach in the form of randomized trials with comparisons of the open versus the laparoscopic approach.

Today, nearly everything we do in a body cavity as pediatric surgeons can be done laparoscopically. The technique has evolved from a novelty to a standard of care in many centers around the world. Even as many senior surgeons haven’t learned the technique and therefore don’t offer it to their patients, most surgeons training today are as facile with laparoscopy as they are with the open approach.

Since we can and do perform nearly every major pediatric surgical procedure laparoscopically, and since many of the approaches have evolved some over the years—past the learning curve—into cost effective operations that rarely take extra time to perform, or in some cases save time, it is worthwhile reviewing our current practices.

This book, then, serves as both an update of current practices and as a manual for how to approach the most common of the pediatric disorders using laparoscopic techniques. It covers the basics of anesthesia, instrumentation and ergonomics and then reviews many of the more commonly performed laparoscopic and thoracoscopic pediatric procedures, including a review of fetal work.

While any book written about such a rapidly evolving technique may miss some of the very newest twists and modifications of technique, it is our hope that most of the contents will serve the readers as a reference for years to come as they care for children with common pediatric surgical problems.

The format is designed to be more readily accessible than other hard backed texts and our plan is to keep this work up-to-date as we plan future editions.

Thom E Lobe

Anesthesia for Pediatric Minimally Invasive Surgery

Laura Siedman

Introduction

With the introduction of laparoscopic techniques, particularly cholecystectomy in adults in the 1980s, a virtual revolution has taken place in surgery leading to tremendous advances in minimal access surgery (MAS) of increasing complexity. The evolution of MAS from novel and creative to standard of care dictates that the anesthesiologist be facile with aspects of endoscopic surgery which directly impact the anesthetic technique including the effects of gas insufflation into body cavities, unique positioning, airway management and postoperative pain issues.

While MAS has necessitated changes in the anesthetic management of adult patients including variations in patient position, avoidance of N₂O, and the use of double lumen tubes for thoracoscopy, these are easily accomplished and thus the impact has not been profound. However, with the advent of MAS for neonates, the pediatric anesthesiologist must now consider how to accomplish and maintain one lung ventilation for thoracoscopy without the benefit of double lumen endotracheal tubes, keep infants warm in the face of cold gas insufflation, avoid hypercarbia in response to CO₂ absorption and avoid abdominal distention that may ensue from bag-mask ventilation upon induction of general anesthesia.

This review will present the anesthetic implications of both laparoscopy and thoracoscopy in infants and children. Because of the unique challenges posed by the two procedures, this review will discuss specific dilemmas and concerns unique to each.

General Considerations

Anesthesia for pediatric MAS begins with a careful history and physical. In particular, derangements in cardiac and pulmonary performance should be sought in order to identify which patients may not be able to tolerate the effects of increased CO₂, one lung ventilation or the reduction in functional residual capacity which occurs with gas insufflation. A coagulopathy may preclude MAS because oozing may limit visibility for the surgeon since blood absorbs light. Control of surgical bleeding may also take more time leading to an increase in morbidity. Plans should be made for postoperative pain control, including a discussion with parents regarding regional anesthesia in appropriate patients should the MAS procedure need to be converted to an open laparotomy or thoracotomy. Premedication should be administered as usual based on patient's age, developmental stage and physical condition.

Induction of anesthesia may be via the intravenous or inhalation route, keeping in mind that both bag-mask ventilation and N₂O may distend the bowel making

intraabdominal visualization difficult or impossible for the surgeon. Bag-mask ventilation, when necessary, should be kept to low peak airway pressures. Nitrous oxide use should be limited to induction of anesthesia so that the bowel lumen is not expanded for laparoscopy and so that oxygenation can be maximized for thoracoscopy. Minimizing bowel gas is so important that it is becoming common to bring neonates with bowel atresias and mechanical obstructions to the operating room within the first day of life, before intraluminal bowel gas becomes prohibitive for laparoscopy.

In general, patients should have their tracheas intubated for MAS because of the duration and location of surgery along with the increase in intraabdominal pressure and the theoretical risk of gastroesophageal reflux. However, it has been suggested that with intraabdominal insufflation, lower esophageal sphincter tone increases as well and therefore the risk of aspiration may not be greater than at baseline even in combination with the Trendelenburg position. Therefore, for brief laparoscopic procedures including diagnostic inspection of the abdomen or examination of the contralateral side during inguinal hernia repair, it may be acceptable to use a laryngeal mask airway in appropriate patients. This is logical since small children are generally intubated with uncuffed endotracheal tubes so that the airway is not completely protected from aspiration even when intubated.

Maintenance of anesthesia is usually performed with a combination of a volatile anesthetic, an opiate and a neuromuscular blocker. Theoretically, halothane may contribute to dysrhythmias in the face of the increased CO₂ imposed by MAS and may be better avoided. Neuromuscular blockade should be maintained throughout the period of gas insufflation since increases in patient tone or breathing movements will decrease the working space for the surgeon by decreasing the pneumoperitoneum from gas egress via the trocar sites. Also, the increased pressure will cause the servo-regulated gas insufflator to cease, further reducing the pneumoperitoneum.

At the conclusion of the operation, exsufflation of CO₂ should be complete so as not to contribute to pneumothorax or diaphragmatic irritation and resultant shoulder pain postoperatively. Trocar sites are either preemptively or upon conclusion infiltrated with local anesthesia (see below). Following thoracoscopy, a chest tube may be left in place or temporarily placed with sustained expansion of the lung and then removed to reduce pneumothorax. Generally, tracheal extubation occurs with the patient awake because of the need for adequate pulmonary toilet following thoracoscopy and the possibility of ileus following laparoscopy.

Cardiorespiratory Effects of Minimal Access Surgery

Surgical exposure for MAS relies on the continuous flow of gas in order to produce distention in the peritoneal cavity and lung collapse in the thoracic cavity. Carbon dioxide is the gas of choice because of it is non-combustible, highly soluble and lacks severe cardiovascular compromise should inadvertent intravascular embolization occur. Both flow and pressure must be regulated to prevent compromise of ventilation or venous return and cardiac output. Changes in cardiovascular function during laparoscopy are affected by insufflation pressure, intravascular volume, patient position and anesthetic agents. Insufflation pressures greater than 20 torr impede venous return leading to a decline in preload while pressures less than 20 torr may augment preload by diverting splanchnic blood to the central compartment. In

adults insufflation pressures if 15 torr result in a modest decline in cardiac and stroke volume index, while maintaining both heart rate and mean arterial pressure. In children, intraabdominal pressures less than 14 torr do not appear to cause adverse hemodynamic effects even in infants less than 5 kg. Although direct measurements of cardiac performance including stroke volume, systemic vascular resistance and cardiac index are not readily obtained in neonates and infants, common clinical parameters including heart rate and blood pressure are not significantly diminished. They may, in fact, increase in response to sympathetic stimulation caused by an increase in CO₂. Brief laparoscopic procedures in children from 1 month to 7 years show no significant hypotension or decrease in heart rate, a modest increase in systolic blood pressure and peak inspiratory pressure and no significant decline in oxygen saturation by pulse oximetry, the usual parameters monitored intraoperatively. The frequently encountered increase in end-tidal CO₂ from absorption across the peritoneum can be easily reduced by an increase in minute ventilation in most patients.

Thoracoscopy may be performed with or without gas insufflation. Lung collapse and the working space is optimized by first producing a pneumothorax via a Veress needle. A valved trocar is then inserted and low flow, low pressure insufflation of CO₂ begins. Ventilation of the lungs often cannot be completely separated in children because selective mainstem intubation with uncuffed and even cuffed endotracheal tubes may allow contralateral "spillover" ventilation. Gas flows between 100 ml/min and 1 L/min with a maximum pressure of 4-6 torr maintain the pneumothorax. This technique is well tolerated in small children, including neonates undergoing thoroscopic PDA ligation. Children with severe lung disease or infiltrative processes which profoundly reduce pulmonary compliance in the past have been thought to be better served with open thoracotomies because biopsy sites did not seal leading to bronchopleural air leaks. However, advances in instrumentation which allow endoscopic stapling have minimized this problem and may allow very sick patients to undergo less invasive procedures with less postoperative pain and splinting. For diffuse or peripheral lesions of the lung, one lung ventilation may not be necessary and maintenance of gas flow alone may provide adequate exposure. Patients who cannot tolerate one lung ventilation may benefit from this technique because small tidal volumes may be delivered to the operative lung while still maintaining an adequate operative space.

Special Considerations

Positioning

Laparoscopy

Perhaps in no other surgical procedure is positioning so integral to the success of MAS. The unique positioning required for laparoscopic procedures entails a host of anesthetic considerations such as positioning the endotracheal tube to avoid dislodgement, avoiding injuries to peripheral nerves from the lithotomy position, proper placement of peripheral intravenous catheters and monitors and the physiologic ramifications of the Trendelenburg or reverse Trendelenburg position. Retraction and exposure is performed nearly completely with the aid of table and patient position since traditional retractors or packs are not appropriate.

Since advanced endosurgical procedures require dissecting and suturing with both hands, the surgeon must often stand centered at the patient's feet. This can be accomplished in one of two ways:

1. Low lithotomy position for patients older than 2 years. For the smallest of these patients this means having a patient a significant distance from the anesthesiologist even with the head of the bed removed. In larger patients care must be taken to ensure that fingers are free of moving parts on the operating table and lower legs are well-positioned and padded to avoid injury to the common peroneal nerve. The risk for deep vein thrombosis must be considered for long procedures and/or those performed on obese patients or those who are hypercoagulable. At risk patients should wear a sequential compression device.
2. Supine, frog-legged for patients less than 2 years. For less intricate procedures that require minimal suturing like pyloromyotomy or ovarian cystectomy, this may be accomplished with the child turned 90° on the table with an arm board added when extra width is required. The endotracheal tube should be taped on the side of the mouth closest to the anesthesiologist with the head turned toward the head of the table so that oral and airway suctioning and inspection of the face is convenient. Also, this avoids having the weight of the drapes on the endotracheal tube, reducing the risk of inadvertent extubation. It is preferable to have intravenous access on the side of the patient nearest the anesthesiologist so that inspection of the site can be done easily. For complicated laparoscopic procedures requiring either multiple trocar sites or extensive suturing, the baby is positioned at the foot of the bed. This may require that circuit extenders are added to the anesthesia circuit since the child's head is a long distance from the machine.

Upper abdominal operations including cholecystectomy, splenectomy and fundoplication employ variations of the reverse Trendelenburg position so that gravity can reduce the bowel from the surgical field. A steep tilt (e.g., 45° for fundoplication) requires the use of a moldable beanbag seat that is clamped to the operating table in order to keep the patient from sliding. Patient blood pressure may be diminished requiring fluid resuscitation to compensate for the decreased venous return due to this position. Combined abdomino-perineal procedures including colon pull-throughs for Hirschsprung's disease and colectomies with perineal anastomoses for inflammatory bowel disease may require a full lower body prep and therefore preclude the placement of intravenous lines and monitors on the lower extremities. Retroperitoneal procedures including adrenalectomy and nephrectomy are accomplished in the lateral position with the kidney rest up. Care must be taken to prevent positioning injuries to the dependent extremities by padding elbows, hips, knees, ankles and the axilla.

Thoracoscopy

With rare exceptions, open thoracotomies are performed with patients in the lateral decubitus position. In contrast, thoracoscopy, like laparoscopy, is performed in a variety of positions to allow the most direct access to the lesion while causing

the lung to “fall away” from the operative site. The operative position is determined primarily by where in the mediastinum the lesion emanates:

- Anterior mediastinum. (e.g., thymectomy, biopsy/resection of malignancies). The patient is supine with the affected side elevated 20-30°.
- Middle mediastinum. (e.g., most lung biopsies, resection of a bronchogenic cyst) The patient is in the full lateral decubitus position.
- Posterior mediastinum. (e.g., neurogenic tumors, esophageal pathology, sympathectomy) The patient is prone with affected side elevated 20-30°

Anesthetic considerations for these procedures are similar to those for open thoracotomies in that bony prominences must be padded. The brachial plexus should be protected from injury by using an axillary roll. When patients are in the prone position, pressure on the globes must be avoided. In addition, the ipsilateral arm and hand is often prepped into the surgical field precluding the use of intravenous lines and monitors in that extremity.

Airway Management

Thoracoscopy is preferentially performed with one lung ventilation of the nonoperative side. This allows the ipsilateral lung to deflate and fall away from the working space. While this is accomplished relatively easily in adults by using double lumen endotracheal tubes, there are no appropriate sized double lumen tubes for children less than about 12-14 years old. Currently, a 28 double lumen tube is the smallest available, too large for neonates and young children less than 30-40 kg. Single lumen tubes with bronchial blockers attached have also been used (Univent tube). An occluding balloon attached to a stylet on the side of the endotracheal tube can be advanced into the nonventilated lung. The smallest available however is a 6.0 internal diameter or 31, also not appropriate for children less than 40 kg. There are however several options for reducing the amount of ventilation to the ipsilateral lung in small children and infants:

1. Selective mainstem intubation: This is facilitated by the use of smaller than usual endotracheal tubes. A cuffed endotracheal tube may offer the advantage of “sealing” the bronchus and reducing the amount of cross ventilation to the operative side. The addition of a cuff requires the use of smaller internal diameter tubes and therefore results in greater airway resistance. A cuff adds about 0.5 mm to the external diameter in its deflated position. Failure to downsize may result in subglottic trauma upon insertion or may cause tracheal tissue ischemia when the tube is withdrawn to its endotracheal position for bilateral lung ventilation. The smallest cuffed endotracheal tube is 3.0 mm internal diameter, which may be too large for some neonates.

Despite these techniques, a controlled pneumothorax with low flow, low pressure gas insufflation is usually required to keep the ipsilateral lung deflated. A right mainstem intubation is easily accomplished since it originates at a less acute angle from the carina compared to the left. However, care must be taken not to advance the tube too deeply since it may obstruct the right upper lobe bronchus. A left mainstem intubation is a greater challenge. It may be accomplished by turning the child's head to

the right side while advancing the tube. Turning the tube so that the concavity faces posteriorly, allowing the bevel to face the right improves the success. Also placing the child in the right lateral decubitus position may be helpful because the mediastinal contents shift to the right changing the conformation of the inlet to the right mainstem bronchus and preferentially allowing passage into the left. It may be necessary to pass a flexible bronchoscope into the endotracheal tube and down the left mainstem. Using the bronchoscope as a stylet, the tube is advanced over the bronchoscope. Flexible fiberoptic bronchoscopes are available as small as 2.2 mm outer diameter (OD). The smallest available with a flexible tip and a suction port is 2.8 mm OD.

2. Fogarty balloon occlusion: After the induction of general anesthesia, a 4-5 Fogarty balloon catheter with stylet is placed in the trachea via direct laryngoscopy. The trachea is then intubated with an appropriately sized endotracheal tube. A swivel adapter is attached to the endotracheal tube to allow continuous ventilation during positioning of the Fogarty catheter. A well lubricated bronchoscope is inserted via the swivel adapter and used to ensure that the endotracheal tube is just proximal to the carina and then to guide the Fogarty catheter into the bronchus to be blocked. This may require manipulation of the patient's head from side to side in order to guide the tip of the catheter to the correct side. The balloon is then inflated and lack of expansion during ventilation is confirmed. The balloon is then deflated, and the catheter is secured along with the endotracheal tube. The balloon should remain deflated until placement of the first trocar to allow the ipsilateral lung to collapse. The balloon is then partially inflated. Carbon dioxide insufflation is begun, forcing the remaining air out of the lung prior to complete inflation of the balloon.

Pain

Both laparoscopy and thoracoscopy cause less tissue trauma than conventional open surgery, thus theoretically less postoperative pain. A reduction in peak intraoperative IL-6 has been reported during laparoscopic pyloromyotomy and ovarian teratoma resection when compared with the open procedures suggesting a reduction in surgical stress. Thoracoscopy offers the advantage of less postoperative respiratory splinting allowing for more effective deep breathing. This results in a decrease in the incidence of postoperative pneumonia and other pulmonary complications. This may offer a particular advantage in patients with serious underlying pathology where vigorous pulmonary toilet is necessary to avoid inspissation of secretions or in whom pneumonia is potentially lethal, as with the immunocompromised patient or the patient with cyanotic congenital heart disease. Though MAS is generally agreed to cause a significant reduction in postoperative pain, as many as 80% of adult patients require postoperative opiates. Several factors, many easily treatable, still contribute to the need for postoperative analgesics, including opiates. Multiple factors can be broken down into two categories:

Pain from Gas Insufflation

It has been hypothesized that gas pressure peaks have a noxious effect on the phrenic nerve, perhaps via stretch caused by distention of the diaphragm leading to endoneural ischemia. Subdiaphragmatic instillation of long-acting local anesthetics have been recommended by some investigators. The acid intraperitoneal milieu caused by the dissolution of CO₂ may have an irritating effect on the phrenic nerve and the peritoneum. Residual intraperitoneal gas may exacerbate postoperative pain both by the direct distention of the abdomen and by prolonging the other aforementioned effects of gas insufflation. Therefore, active suction of the peritoneal cavity following laparoscopy should be done to minimize residual gas. Gas properties including temperature and humidity have been purported to be clinically relevant in the severity of postoperative pain. It has been suggested that while cool gas is warmed so rapidly as to have little physiological effect, dry gas may have a significant damaging effect on exposed membranes. Warming and humidifying gas for insufflation may reduce postoperative pain.

Wound Pain

Preemptive analgesia via infiltration of local anesthesia has been recommended to reduce trocar site pain. A tumescent technique has been reported in the plastic and dermatologic surgery literature and advocated by some pediatric surgeons. Infiltration of large volumes of dilute local anesthetics eg 1/10-1/8% Lidocaine with 1:400,000 or 1:1,000,000 epinephrine to the trocar sites prior to insertion is reported to be safe and effective for prolonged postoperative analgesia. The addition of a vasoconstrictor can provide analgesia for up to 18-24 hours. The use of rectal acetaminophen and non-steroidal anti-inflammatory drugs like ketorolac have been advocated for their opiate-sparing effect. While opiate analgesics should be made available and may be necessary in the early postoperative period in some patients, patient-controlled analgesia and neuraxial analgesia are not needed.

Complications of Minimal Access Surgery

The complications of MAS can be divided into two categories; those specifically attributable to the insufflation of gas into a body cavity or the specific instruments used to carry out the procedure and those which are not unique to the mode of surgery but rather to the nature of the procedure itself. A specific risk of MAS that should concern the anesthesiologist is the effect of gas pressure on hemodynamic and respiratory function. In neonates undergoing thoracoscopy for resection of malformations of the lung, ligation of a tracheoesophageal fistula and repair of esophageal atresia, one must be aware that a controlled pneumothorax is routinely used, albeit at low pressure, in order to maintain the working space. This may compromise cardiac output and oxygenation profoundly and therefore a constant dialogue must continue between the anesthesiologist and surgeon so that reexpansion of the lung is performed intermittently.

Gas insufflation for laparoscopy may also reduce venous return and compromise cardiac output if not regulated to pressures less than 14 torr in children and 12 torr in neonates. This may require fluid resuscitation and changes in the degree of reverse Trendelenburg position allowed. During procedures in the upper abdomen, particularly around the esophageal hiatus (e.g., fundoplication or Heller myotomy

for achalasia), it is possible for gas to dissect into the mediastinum or subcutaneously leading to crepitus or pneumothorax postoperatively. Excessive subcutaneous emphysema of the neck may compromise ventilation and therefore a leak around the endotracheal tube should be confirmed before extubation of the trachea. Also, the hot tip of the harmonic scalpel may violate the diaphragm in upper abdominal procedures leading to a tension pneumothorax. This is heralded by an increase in peak airway pressure and decreased oxygen saturation. The surgeon may note a bulging hemidiaphragm.

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Instrumentation in Pediatric Endoscopic Surgery

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Introduction

The success of modern surgery is dependent on the availability of good equipment and instruments. This dependence increases along with the degree of sophistication of the surgery performed. Endoscopic surgery is sophisticated. Imaging is obtained through a video-circuit while the actual operation is done through a limited number of small holes. Moreover the working space is much less self-evident than in open surgery. It has to be created and maintained. Endoscopic surgery has opened the field of virtual reality in surgery. It has been proven that surgery is possible by looking at the virtual images of video-projection. The next step is of course remote surgery and investigations in this direction are well under the way but will not be discussed in this chapter.

This chapter gives an overview of the basic equipment and instruments that should be available:

Disposable versus Nondisposable Equipment and Instruments

- Video-circuit
- Telescope
- Types
- Robotic assistance
- Light source and cable
- Camera
- Monitor
- Video-recording
- Creation and maintenance of a working space
- Insufflation or not
- Insufflators
- Access
- Terminology
- Cannulae
- Trocars
- Cannulae without trocar
- Cannula insertion
- Cannula fixation
- Porthole enlargement

- Suction and irrigation
- Retraction
- Types
- Holding of retractors
- Working instruments
- General considerations
- Basic instruments
- Dissecting and grasping
- Holding
- Scissors
- Clipping and stapling
- Ligature and suture
- Specific instruments
- Instruments of energy supplying systems
- High frequency electrosurgery (HFE)
- Ultrasonic surgery
- Removal of organs/tissue

Disposable and Re-Usable Instruments and Equipment

Many instruments and parts of equipment are available in a disposable, a non-disposable or in a semi-disposable form. Even telescopes nowadays can be bought in a disposable form. The advantage of disposables is that each instrument is new, which means clean, sterile, and well working. Moreover disposables are in stock, making spares readily available. The disadvantages of disposables are: the purchase costs, the problem of storage before use, and the waste problem after use. Re-usables have to be cleaned, sterilized and packed, and have to be serviced. Moreover it takes longer before a disposable instrument can be produced in a re-usable form, as a longer life has to be guaranteed. As a result a number of instruments are only available in disposable form, e.g., endoscopic staplers and ultrasonic shears.

There is a big difference between the USA and Europe in the extent of use of disposables. Many more disposables are used in the USA, while in Europe predominantly re-usables are used. This difference seems to be mainly based on a difference in healthcare financing and in the legal system dealing with liability.

The telescopes for endosurgery at present are rigid telescopes. They contain a rod lens system as optical system, and glass fibers for the transmission of light. There is a wide variety of telescopes available differing in diameter size from 1 mm to 10 mm and in angulation from 0° to 70°. The thinner telescopes are also shorter. The quality of the telescopes in terms of visualization and light transmission is inversely related to the diameter of the telescope.

To start with endoscopic surgery in children, it is advisable to start with 5 mm diameter telescopes (to be used in concert with 6 mm diameter cannulae) as these telescopes give good view and allow for sufficient light transmission for most operations in children. Moreover as it is also advised to start with 5 mm diameter instruments (also to be used in concert with 6 mm diameter cannulae), the telescope can be moved to different port sites. After gaining experience, the surgeon can decide whether smaller telescopes give a sufficient view.

It is advisable to use 30° telescopes for most operations. Telescopes with an angle allow for looking behind structures. Port sites during laparoscopy are difficult to see except when an angled telescope is used. Moreover as the axis of view differs from the axis of the telescope and from the axis of the working instruments less entanglement will occur. Telescopes with a flexible tip containing the chip have become available. The degree of the angle therefor can be changed. Unfortunately these new telescopes have a diameter of 10 mm. See also the chapter on ergonomics.

Cleaning

It is important to clean the tip of the scope immediately after the operation. If dirt is allowed to stay on the tip of the telescope for some time it will not only erode the surface but it also will dry out and automatic rinsing machines will not be able to get it off. Needless to say that the quality of the image will be affected.

Robotic Assistance

It is a matter of time before the cameraman in most hospitals will have been replaced by a robotic voice controlled arm. The advantage of a robotic controlled arm is its steadiness and its tirelessness. Moreover the camera held by a cameraman is often in the way of the surgeon. A robotic assistant is already on the market for some time, but the cost of the system and its heaviness are important drawbacks at present.

Light Source and Cable

There have been tremendous improvements in the light sources. A xenon 300 watt light source works very well. The light source should be set at maximum capacity in the non-automatic mode as modern cameras have a fast automatic shutter built-in. It should be realized that cold light does not exist. The temperature at the end of the light cable rises up to 225° C within seconds and at the end of the telescope up to 95° C within 15 minutes. The cable should therefore always be attached to the telescope and wiping the lens clean against surrounding tissues should not be done.

It is important to have good quality light cables adapted to the telescope to be used. The thickness of the cable should match the thickness of the light inlet of the telescope (Figs. 2.1A and 2.1B). Thick cables will not produce more light but more heat, while thin cables will not transport enough light.

Camera

The quality of the cameras has been greatly improved over the years. Instead of a single chip, more modern cameras have three chips, one for each of the three primary colors. Moreover the newer cameras allow for contrast enhancement. Whether these recent improvements are in balance with the increase in price remains to be seen.

Good quality cameras are equipped with a 22-50 mm parfocal zoom, which means that the image can be enlarged without need for refocusing. It should be realized however that the greater the enlargement, the less perception of depth, the less resolution and the less illumination. Before starting the operation, each telescope-camera combination should be focused.

Each camera has a camera control unit with or without contrast enhancement and with or without automatic white balancing. If white balancing is not automatic

then this has to be performed after the telescope has been attached to the camera and light source.

Most of the cameras in use give a two dimensional image. It has been thought that three-dimensional systems would greatly improve task performance, but this has not been substantiated yet, at least with the first generation three-dimensional systems. The second generation is more promising. See also the chapter on ergonomics.

Monitors

Most endoscopic surgeons use large (50 cm) color monitors. Disadvantages of these monitors are that they are heavy and that they are difficult to put in an optimal position. Lightweight flat screens are being produced. Their position will be much easier to adjust to ergonomic demands. Projection of the image on a sterile white plate that can be put anywhere is superior from the ergonomic point of view, but has a lower resolution than the standard video-circuit. Moreover any light in the operating room interferes with the quality of the picture. Lightweight mini-screens mounted on a pair of glasses are already on the market. Such a system could be superior from the ergonomic point of view, but the actual resolution is far less than the resolution of the standard video-circuit.

Video-Recorder

Basically three different qualities are in use today: betacam, SVHS and VHS. SVHS gives reasonably good quality and has the advantage that the recording system is widely available. The matter of storage of video-recordings has not been solved yet. It leaves little doubt that with time all recordings will have to be stored for a defined period of time as part of the electronic patient chart. For the time being, it seems wise to record all endoscopic operations and to store the film for at least 6 months. To make storage and retrieval simple, only one operation per tape should be recorded.

The Creation and Maintenance of a Working Space

Insufflation or Not?

In the chest a working space can be obtained by allowing the lung to collapse. This can be partially achieved by opening the chest but intermittent positive pressure ventilation will prevent total lung collapse and will hamper the endoscopic operation. An elegant solution for this problem is unilateral lung ventilation, but this is rather difficult to achieve in small children. Moreover unilateral lung ventilation in children is often poorly tolerated. Another way of creating sufficient space in the chest is the induction of an artificial tension pneumothorax with CO₂ with a pressure of 5-8 mm Hg. A lung retractor may assist in keeping the lung out of the way. If an artificial tension pneumothorax is required, then all ports should be CO₂ tight and should therefore have a valve.

In the abdomen a working space can be created by means of abdominal wall lifting and allowing air to enter through open ports. Various lifters are on the market (Fig. 2.3). Despite the elimination of the disadvantages of a CO₂ pneumoperitoneum (elevated intraabdominal pressure, use of CO₂), abdominal wall lifting has not gained wide acceptance yet, the main problem being a less optimal working space.

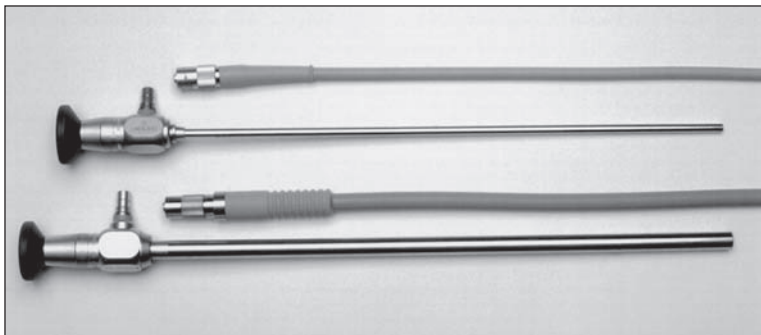


Figure 2.1A. Five mm and 10 mm telescope. Note the difference in thickness of the light cables.

Lifting devices rather tent the abdominal wall while a CO₂ pneumoperitoneum creates a dome.

When no gas is required for the creation of a working space, there is no need for valved cannulae. Instead small thoracotomy or laparotomy incisions can be carried out allowing classic instruments to be brought in directly.

Insufflators

Most insufflators use CO₂ as an insufflation gas. Both maximum pressure as well as flow can be adjusted. Because of the negative effects of an elevated intraabdominal pressure on systemic and local hemodynamics, lung compliance and intracranial pressure, the maximum pressure limit should be set as low as possible. Most operations in children can be well performed using a pressure not higher than 8 mm Hg. If temporarily a higher pressure is required, this should be set back as soon as possible. To be able to obtain a good working space with a low intra-abdominal pressure, optimal muscle relaxation is required. As far as flow is concerned, a low flow, e.g., 2 L/minute is sufficient when the cannulae do not leak. Major gas leaks should be prevented as this will lead to higher CO₂ consumption with danger for hypothermia. If higher flows are required, the gas used should be preheated and humidified. In small babies, a low flow should be used, as the volume of the abdominal cavity is small, e.g., only about 400 ml in the newborn. A high flow will surpass the preset maximum pressure, as insufflators do not measure the pressure continuously but intermittently.

There are insufflators on the market in which pressure in the system is kept constant. Whenever pressure is augmented, e.g., by pressure onto the abdomen, a valve in these insufflators is opened and CO₂ is allowed to escape. As gas from the patient is allowed to enter the insufflator, filters have to be used. Moreover such a bi-directional insufflator uses more CO₂ and predisposes therefore for hypothermia. Such a system should therefore only be used in concert with preheating and moistening of the CO₂.

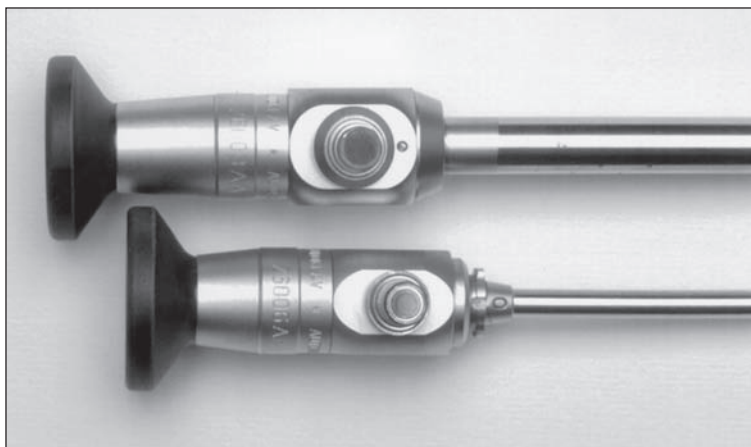


Figure 2.1B. Five mm and 10 mm telescope. Note the difference in diameter of the light inlet. The cable to be used should have the same diameter.

Whatever insufflator is used, it is advisable to place insufflators at the same height as the patient to prevent back flow of condensation fluid from the tubing into the insufflator.

Access

Terminology

The terms port, cannula and trocar are often used as synonyms. In the context of this chapter, the term trocar will be used for the removable spike or obliterator in the cannula, the term cannula will be used for the cannula without trocar, and the term port for cannula with trocar.

Cannulae

Insufflation Stopcock and Valve (Fig. 2.2)

There are cannulae with and without a stopcock for CO₂ insufflation and cannulae with and without a valve. Certainly at the beginning of gaining experience in the field of endoscopic surgery, it is advisable to standardize as far as possible. So all cannulae should have a stopcock for CO₂-insufflation and should have a valve. The valve should be easy to open for the introduction or removal of items, e.g., needles. So-called automatic valves that open while inserting an instrument but cannot be kept open while retrieving an instrument are cumbersome as they interfere with the removal of items such as needles or pieces of tissue. Some cannulae have a partial membrane as a valve. When no instrument is inside, these cannulae leak CO₂. To prevent leakage when no instrument is present a blunt obliterator should be inserted.

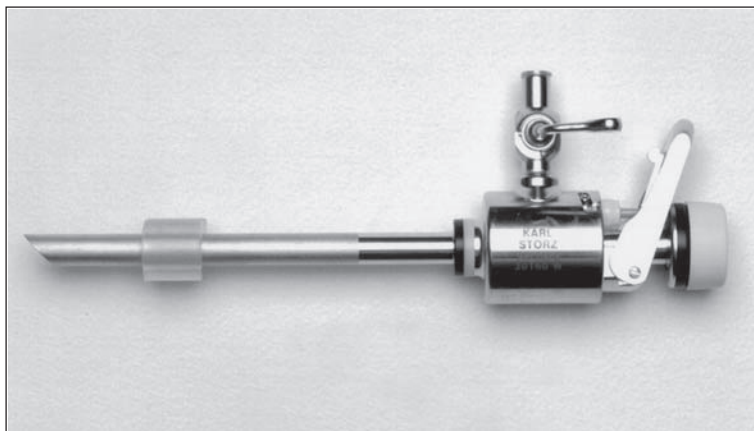


Figure 2.2. Standard 5 mm re-usable cannula with stopcock and valve that can be opened. Note the cuff of silicone around the cannula, allowing for fixing the cannula with a suture. This cuff can be moved up and down so that the length of the interior part can be adjusted.

Diameter

It is advisable to start building up experience in endoscopic surgery with cannulae and corresponding telescopes and instruments of the same diameter. It is very annoying if one wants to change the telescope or an instrument to a different cannula position and to find out that the cannula is too small. Using the same diameter of cannulae allows for changing telescope and instruments to all available cannula positions. It is suggested to start with a diameter of 6mm for the use of 5 mm diameter telescopes and instruments. Telescopes with a diameter of 5 mm give a good view and allow sufficient introduction of light. The 5 mm-diameter arsenal of instruments is extensive and most of these instruments nowadays are insulated. If the difference between the inner diameter of the cannula is too small in relationship with the outer diameter of the telescope of instruments, then too much resistance may be encountered which hampers movements, tactile feeling, CO₂ insufflation, and predisposes to cannula dislodgment.

Some instruments are not available yet in a 5 mm-diameter variety such as endoscopic linear staplers, which require a 12 mm diameter cannula. Also bags to be introduced for the removal of tissue require larger cannulae. The EndoCatch I bag (Autosuture) requires a cannula of 11 mm and the EndoCatch II bag a cannula of 15 mm.

Two and 3 mm instruments have become available. The 2 mm instruments are fragile and bend easily. Moreover the beaks of these instruments are so narrow that accidental perforation may easily occur and firm grasping will cause tissue damage. In contrast, 3 mm instruments to be used in concert with 3.3 mm cannulae are quite strong and are less likely to cause accidental perforation. Most 3 mm instruments are now available in an insulated form and most of the operations in children



Figure 2.3. Re-usable scissors: 5 mm, 3 mm, and 2 mm diameter. The total length of 3 and 2 mm scissors is shorter than of 5 mm scissors but the metal end of the 3 mm diameter scissors is as long as the end of 5 mm diameter scissors. The metal end of 2 mm scissors is also relatively long.

can be done with 3 mm instruments. The total 3 mm arsenal however is much more limited than the 5 mm arsenal. A Babcock for example is not available yet. Although the diameter of the instruments has been miniaturized, the uninsulated length of the end of the instruments has remained more or less the same. (Fig. 2.3) This means that the telescope has to remain quite remote from the area to be operated in order to keep the whole uninsulated end of the instrument into view in order to avoid unintentional coagulation of surrounding tissues. Small diameter instruments may be useful as an extra instrument for example to put tension on a structure that is being tied.

Length

The length of the cannula should depend on the thickness of the body wall to be pierced, but here again it is advantageous to standardize as far as possible. In general cannulae for use in children may be shorter, not only because of the thinner body wall but also because of the limited diameter of the working space. Cannulae in children should pierce the body wall only for a short distance.

Transparency

There are disposable transparent cannulae on the market (Fig. 2.4). This allows for inside viewing of the cannula. Moreover retained material in the valve can be seen from the outside.

Trocars

The purpose of a trocar is to facilitate the introduction of a cannula or to obliterate the cannula if only a ring like valve is present.

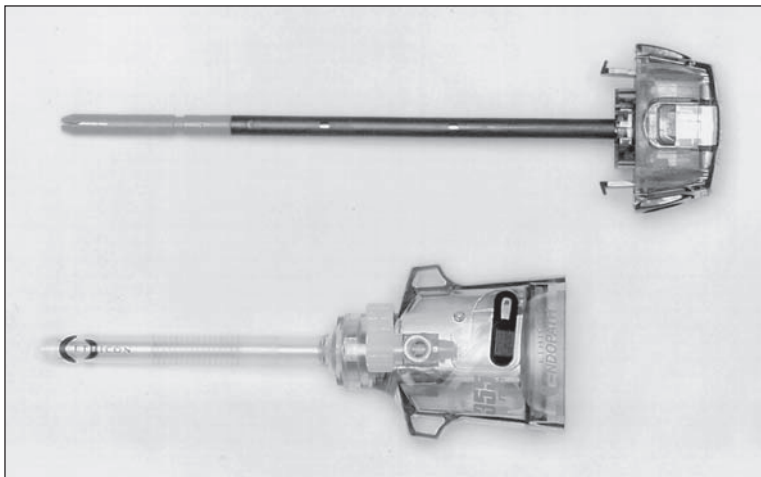


Figure 2.4. Disposable 5 mm cannula and trocar. The cannula is transparent. The trocar has a conical end with a narrow retractable blade at the tip.

There are several trocar types: sharp pyramidal, sharp conical, eccentric and blunt conical (Fig. 2.5). The classic sharp pyramidal trocar is quite traumatic, especially when inserted in screwing way. As a result, leakage of gas and dislodgment occur easily. The sharp conical trocar is less traumatic as it dilates the tissues. Leakage of gas and dislodgment of the cannula is less likely to occur, but the insertion requires substantially more force to pierce the body wall. Eccentric trocars make a slit-like hole and require less force to be inserted. Blunt conical trocars are ideal when a cannula is inserted using an open technique. Due to its conical form, the opening in the body wall can be somewhat smaller than the diameter of the cannula, which allows for fixation through dilatation. Even when inserted in an open way, it is advisable to insert the cannula together with a trocar, which in this circumstance should be blunt. This will not only prevent damage of tissues caused by the edge of the cannula, but allows a smaller hole for insertion. The trocar not only has a smaller diameter than the inside diameter of the cannula, but also has a conical tip.

Cannulae without Trocar

A new nondisposable cannula with a screw winding on its outer surface and blunt starting point has been developed for insertion without a trocar (Fig. 2.6). A small fascial incision is made after which the cannula is screwed in clockwise direction. This process can be supervised by using a telescope inside the cannula at the same time. By doing so the tissues are not cut but pouched away. The cannula is removed by screwing in counter clock direction.

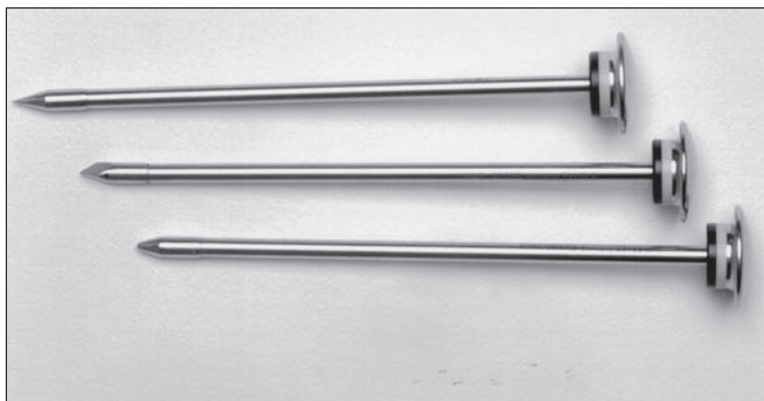


Figure 2.5. Different trocars: upper: sharp conical; middle: sharp pyramidal, lower: blunt conical.

Cannula Insertion

First Cannula

For the introduction of the first cannula, one can choose between open insertion through a minithoracotomy/minilaparotomy or closed insertion after introduction of a Veress needle and the creation of a pneumothorax or peritoneum. Such a Veress needle has a beveled sharp end, which is blocked with a blunt pin by means of a spring mechanism as soon as the piercing resistance fades (Fig. 2.7A). As soon as the working space is created, the Veress needle is withdrawn and the first cannula is inserted, usually by means of a sharp trocar. Several disposable cannulae are sold with a sharp trocar in which the trocar end becomes covered with a shield as soon as the piercing resistance gives away. One should not rely too much on this mechanism as the shield may only cover the sharp trocar end with a certain delay. Also the edge of the shield itself is quite sharp and may therefore damage internal structures.

Veress needles are quite delicate instruments. They should be sharp and they should have a perfect working spring mechanism. For all these reasons it may be better to use disposable Veress needles only. In any way if re-usable Veress needles are used, one should make sure that the needles are still in perfect condition, which means that the life cycle of the needle should be controlled.

In the Step system, a disposable sleeve over a Veress needle is inserted en block (Fig. 2.7A). The Veress needle is then removed leaving the sleeve in place. A cannula with a blunt trocar is then inserted through the sleeve thereby radially dilating the sleeve providing firm fixation (Fig. 2.7B). The Step system is available in a complete disposable and in a semidisposable version. In the latter, only the sleeve and cannula valve are disposable.

Most endoscopic surgeons use an open method for the introduction of the first cannula in order to prevent the rare but often life threatening complications of vascular or hollow viscus perforation by the Veress or the blind insertion of the first port.

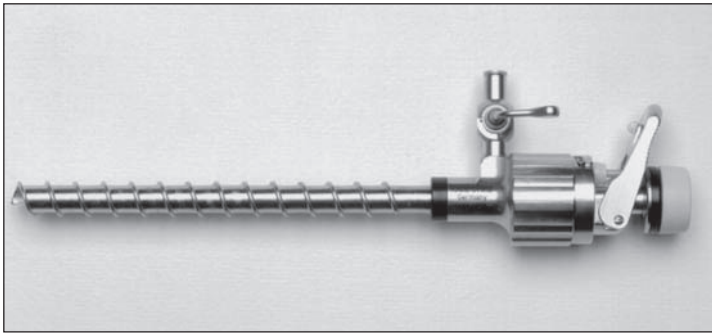


Figure 2.6. Cannula to be introduced without trocar. Note the self-tapping spiral. During the insertion a telescope can be put inside the cannula allowing for visual control.

Secondary Cannulae

Secondary cannulae are always inserted directly but under endoscopic control. It is advisable to make a small through and through stab incision using an 11 mm blade as this will reduce significantly the amount of pressure required to introduce the port, thereby decreasing the risk for accidental damage of internal structures. To avoid internal damage by the sharp end of the trocar during the insertion, some trocars have a shield that covers the sharp end of the trocar immediately after piercing the cavity to be entered. Such shield however may fail to cover the sharp end or may cause damage by its own sharp edge (Fig. 2.8). Other disposable trocars have small blade of a knife at the end of the trocar, which retracts as soon as the piercing resistance is lost (Fig. 2.4).

Cannula Fixation

Prevention of dislodgment of cannulae is a great problem in endoscopic surgery, the more so in children because of the thinness of the body wall. Several solutions have been proposed.

Some cannulae have been sandblasted (Fig. 2.2) or have a screw-like structure on the outer surface (Fig. 2.9), but the screw winding may also be a separate device. These solutions are not very effective. Moreover screw windings either as part of the outer surface or as a separate device in fact enlarge the diameter of the porthole. No hybrid systems, e.g., metal cannula and synthetic screw should be used in order to avoid capacitive coupling and related HFE accidents.

The Hasson port has an adjustable cone on the outside. The port is introduced in an open way. The cone prevents the cannula from being pushed in while suturing of the fascia to the cone prevents the cannula from being pulled out.

A simple and effective way of fixing cannulae is to glide a 1 cm synthetic catheter of appropriate inner and outer diameter over the shaft of the cannula and to stitch this sleeve to the fascia or skin (Figs. 2.2 and 2.8). The sleeve should fit properly but should also allow for adjustment of the dept of the cannula. It is advisable to use silicone and not latex catheters for this purpose, as the patient may be or may become allergic to latex.

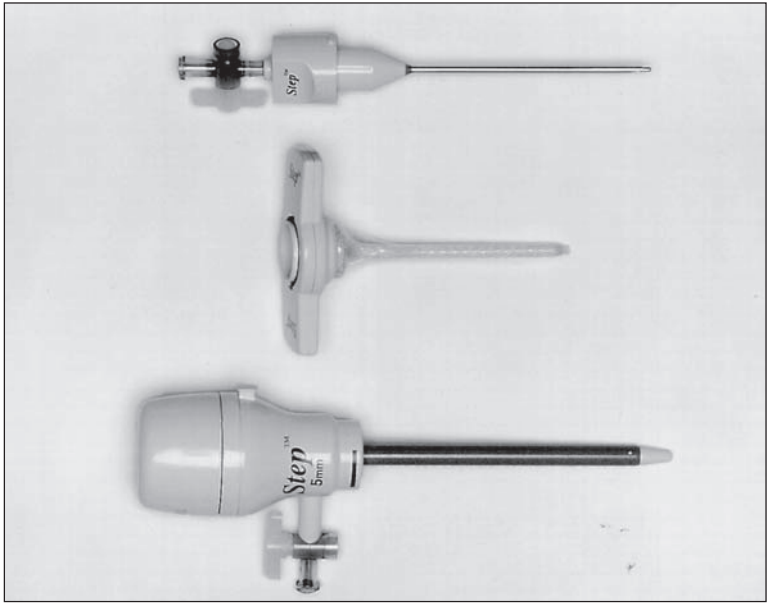


Figure 2.7A. Step® system (disposable) Veress needle, radial expandable sleeve, and cannula with trocar Veress needle in the radial expandable sleeve (upper), port in the sleeve (lower).

Another way of firmly fixing the cannula is to suture the stopcock to the fascia or skin and to tape the tie against the cannula at its basis with a strip of sterile tape (Fig. 2.10).

Suturing the stopcock or sleeve to the skin in areas where the skin is relatively mobile against the underlying fascia predisposes for pulling out of the cannula. This is especially a problem in small babies. Moreover, in small children the cannula may not be inserted deeply as this will further reduce the already limited working space.

There is a disposable cannula on the market with an inflatable balloon at its end and a synthetic plate at the outside to be compressed against the wall. Unfortunately these cannulae have an 11 mm diameter and the part of the cannula to reside in the abdominal cavity is rather long thereby limiting the working space.

The Step system gives good fixation through radial dilatation. However, in lengthy procedures in small babies it is advisable to use additional fixation, e.g., suturing and tape.

Porthole Enlargement or Reduction

Sometimes it may be necessary to enlarge a porthole, e.g., when the appendix appears to thick to be taken out through the inserted 6 mm-diameter cannula. In such an event, the 6 mm-diameter cannula can be replaced by an 11 mm diameter cannula using a dilatation set (Fig. 2.11). In the 6 mm-diameter cannula, a 5 mm-diameter probe is inserted. The surrounding skin and if necessary also the

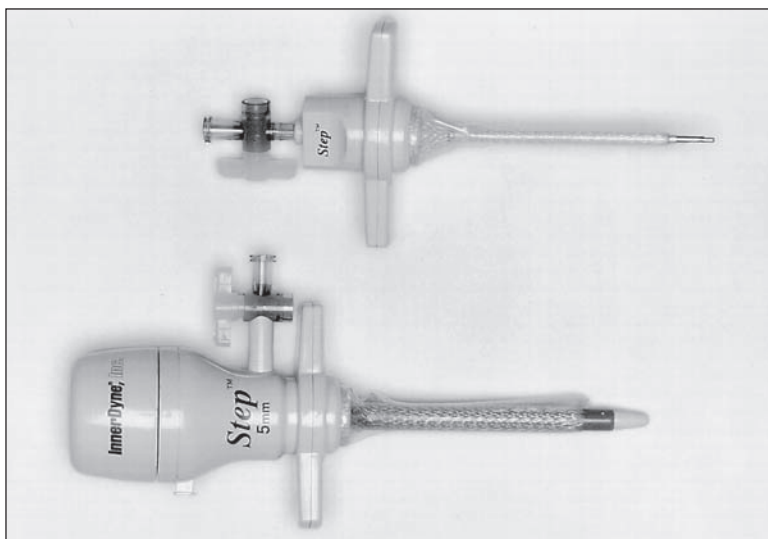


Figure 2.7B. Step[®] system (disposable) Veress needle, radial expandable sleeve, and cannula with trocar Veress needle in the radial expandable sleeve (upper), port in the sleeve (lower)

surrounding fascia is incised. Next an 11 mm diameter cannula with inside a dilator is glided over the probe and is thus inserted.

The sleeve of the Step system allows for the introduction of several different sizes of cannulae (Fig. 2.7).

Adaptation of a large cannula to be used for smaller diameter instruments can be easily achieved by using reducers, which are available for both disposable and non-disposable systems.

Suction and Irrigation

In contrast to open surgery in which a swab with a gauze can immediately restore vision during bleeding or can immediately clean leakage from the bowel, endoscopic surgery largely depends on suction and irrigation for these matters. Moreover as the amount of light that can be brought in endoscopic surgery is limited and blood absorbs light, blood even in areas remote from the direct area to be operated upon has to be removed in endoscopic surgery. Vision in endoscopic surgery is also hampered by smoke produced during the use of HFE.

Suction in endoscopic surgery faces a number of problems. Endoscopic suckers are relatively small, as they have to fit in the cannulae used, yet they should be able to remove blood clots. The sucker instrument therefore should have the largest possible opening at its end. Additional smaller openings along the shaft are not warranted as they are too small for the aspiration of blood clots and as they interfere with forceful aspiration at the tip. Larger blood clots have to be mechanically fragmented before they can be aspirated. This means that the aspiration force should be quite

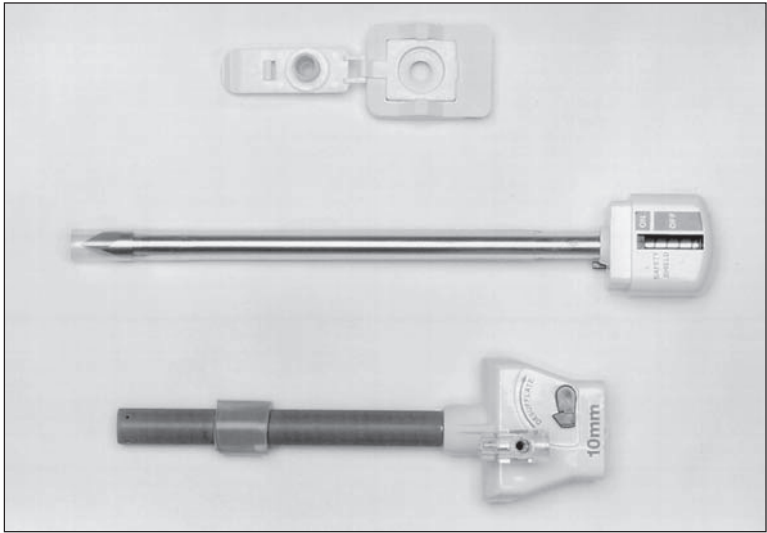


Figure 2.8. Disposable cannula and trocar. The trocar has a shield covering the sharp end. The cannula has a self-cut silicone ring to suture the cannula to the surrounding skin or fascia. Note also the reduction cap so that this 10 mm cannula can also be used for 5 mm instruments.

high but this will interfere with the working space by concomitant removal of the insufflated gas unless the aspirator opening is kept below the CO₂-fluid level. High aspiration pressures will also result in aspiration of the surrounding tissues, thereby blocking the suction opening. This can be prevented to a certain extent by using short bursts of suction or by using a suction apparatus that has an automatic interrupter. Of course the suction force should be easily adjustable.

Irrigation is also very important in endoscopic surgery as it replaced gauze swabbing. Moreover it can also be used to mechanically disrupt clots. Experienced endoscopic surgeons, however, try to avoid liberal use of irrigation because once the operative field has become thoroughly wet, it is hard to get it dry again and this interferes with vision and dissection. The volume of fluid to be injected should be automatically adjustable. As an irrigation fluid usually NaCl 0.9% is used. To prevent hypothermia, the irrigation fluid should be preheated and kept warm.

There should be a control panel indicating:

- suction pressure
- rest volume of the suction bottle
- irrigation pressure
- rest volume of the irrigation bottle
- temperature of the irrigation fluid

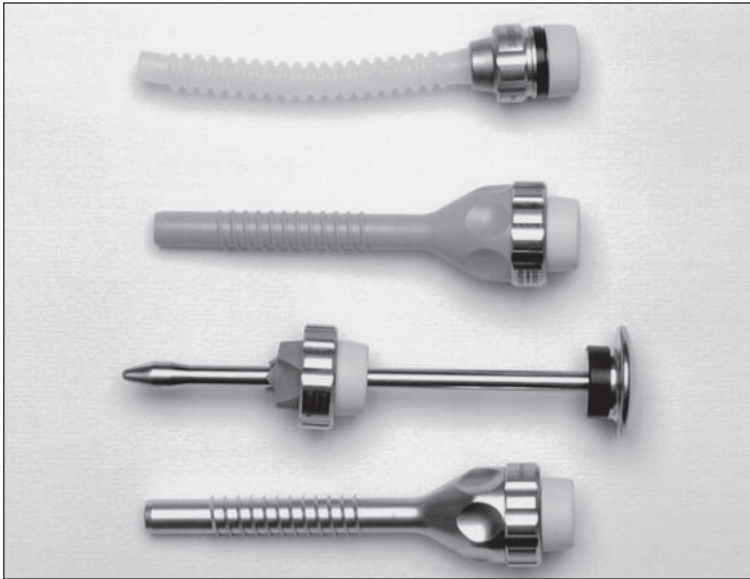


Figure 2.9. Short cannulae with outside winding. The upper two cannulae are of synthetic material while the lower one is of metal. The upper cannula is of soft material. These short cannulae can be used with or without a valve. They may be convenient for thoracoscopic work.

Retractors

As in open surgery retractors in endoscopic surgery are very important. In open surgery, the retractors are usually rather large. Moreover they are under continuous vision. As a result damage to the tissues to be retracted rarely occurs. In endoscopic surgery, the diameter of the retractor has to fit in a cannula and the retraction capacity of many retractors is therefore rather small. Moreover due to the limited viewing field, endoscopic retractors are usually not continuously seen. For these reasons endoscopic retractors can easily damage the surrounding tissues and particularly the liver and spleen. Fan retractors to be opened in the body cavity have been developed allowing for the retraction of larger areas, e.g., the liver, but the opening and closing of the fan should be performed carefully and under vision as damage to the surrounding tissues may easily occur (Fig. 2.12). Moreover the opened fan of these retractors may turn along the longitudinal axis and may therefore cause damage. Retractors to be used in endoscopic surgery should be manufactured in such a way that the degree of rotation can be controlled and maintained externally. The assistant should not hold such a retractor, as accidental advancement or rotation may occur. Instead, the outside end of the retractors should be kept in a fixed position by a holding device.

Ingenious nondisposable retractors with diameters of either 5 and 3 mm are on the market which are introduced in a straight position but of which the inner end

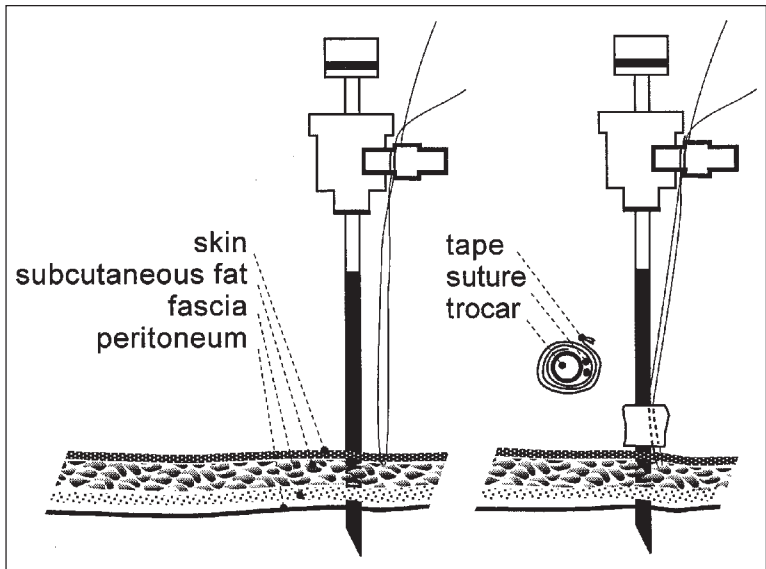


Figure 2.10. Cannula fixation: the stopcock is sutured to the skin and the cannula together with the suture is taped at the entry area. (Reprinted with permission. Bax NMA, van der Zee DC Trocar fixation during endoscopic surgery in infants and children. *Surg Endosc* 1998; 12:181-182).

can be shaped by turning the outside end. Depending on the instrument this shape can be a J, a triangle or a circle (Fig. 2.13). A disadvantage of these retractors is that they are rather difficult to clean.

Retraction can also be provided by trans-body wall stay sutures, but inadvertent outside pulling may damage the tissues under traction. Another way of getting retraction is to put a vessel loop around tubular structures and put traction on the ends of the loop with a forceps.

Sometimes an endoscopic grasping forceps can be used as a retractor. In anti-gastroesophageal reflux surgery for example, the left lobe of the liver can be kept out of the way by inserting a grasping forceps through a cannula high in the epigastrium underneath the left lobe of the liver and grasping the most anterior part of the hiatus.

Working Instruments

General

Each instrument has a handle, shaft and end.

Handle

Several handles have been constructed. Most instruments have a grip handle. Some handles can be locked (Fig. 2.14).

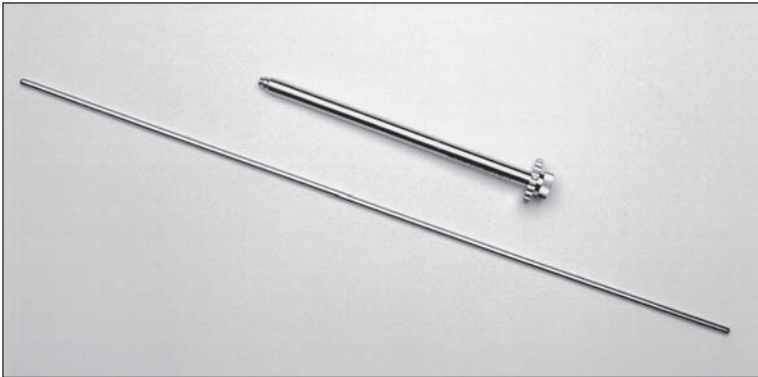


Figure 2.11A. Dilatation set. The 5mm bar is inserted in the 5mm cannula which is then removed. The 10mm sleeve is then inserted in a 10mm cannula. Sleeve and cannula are then glided over the 5 mm bar. Note the somewhat conical form of the tip of the sleeve. The winding at the tip of the sleeve also facilitates insertion. Removal of the 5 mm bar completes the procedure.

Length

The optimal length of an endoscopic surgical instrument has to be determined.

End

Innumerable ends have been created for all kind of purposes. Especially when used in children, where the manipulation angle may be smaller than 60° , it is advantageous when the end of the instrument is curved so that its point is easier to see.

Degrees of Freedom of Movement

Most endoscopic surgical instruments have four degrees of freedom of movement.

Basic Instruments

Dissecting and Grasping Forceps

As a dissecting and grasping forceps a Kelly type forceps is ideal (Fig. 2.15). For running the bowel, e.g., for checking whether there is a Meckel's diverticulum, a forceps with a broader atraumatic beak is more appropriate (Fig. 2.16). Special bowel forceps do exist.

Holding Forceps

Forceps that have to hold tissues for a longer period of time should have a ratchet type handle in order to secure the holding grip. One should be very careful in choosing the type of the beak. Indeed in children, forceps with a traumatic end have limited use. These forceps can only be used to hold strong tissues, e.g., the diaphragm. If they are used to hold stomach or bowel, the wall of these structures can easily be damaged. For continuous traction on stomach or bowel an atraumatic beak, e.g., Babcock, should be used. If larger parts are to be grasped, the Babcock should have a rather long beak. Sometimes a forceps is called atraumatic while it has multiple teeth (Fig. 2.17).



Figure 2.11B. Assembled dilatation set. The 5mm bar is inserted in the 5 mm cannula which is then removed. The 10 mm sleeve is then inserted in a 10 mm cannula. Sleeve and cannula are then glided over the 5mm bar. Note the somewhat conical form of the tip of the sleeve. The winding at the tip of the sleeve also facilitates insertion. Removal of the 5 mm bar completes the procedure.

Forceps may be reasonably atraumatic when used in adults but are traumatic when used in children. No instrument is forbidden but the surgeon is responsible in case something happens.

Scissors

As in open surgery two types of scissors are used: dissecting scissors and scissors to cut ligatures or sutures. If available, curved ends are preferable. For dissection a Metzenbaum type scissors is a good choice (Fig. 2.18). No microdissecting scissors should be used for ordinary work as the blades of these scissors are quite pointed with higher chance for accidental damage. For cutting ligatures and sutures hook type scissors is ideal (Fig. 2.18). These scissors enclose the suture or ligature ends completely before cutting so that the thread cannot escape during cutting. These hook scissors can also be used for cutting tough structures such as the base of the appendix. In the latter case one should use the tip of the blades, as the tip will grip the tissue to be cut not allowing it to escape. Scissors can also be used for monopolar HFE, but the heating of the blades will blunt them easily, especially when they are used with the blades open.

Special Instruments for Special Operations

A number of instruments have been developed for special operations. For pyloromyotomy for example a special knife as well as a spreader have been developed (Fig. 2.19).



Figure 2.12. Fan retractor to be opened inside the body. The retractors easily cause damage.

Clipping and Stapling

Titanium clips, not interfering with magnetic resonance imaging, are available and can be fired using either nondisposable or disposable instruments. Most nondisposable instruments for clips are 10 mm diameter instruments for 10 mm clips (Fig. 2.20). Such an instrument in a 5 mm variety is difficult to find. Then and 5 mm diameter multi firing disposable instruments are available. Nowadays two kinds of 5 mm clipping instruments are available. Although both are used on concert with a 6 mm cannula, the clips have different lengths.

All stapling devices for use in endoscopic surgery are disposable, but can be reloaded several times in the same patient (Fig. 2.21). They are used for concomitant stapling and cutting. Depending on the thickness of the tissue to be stapled and cut two different cartridges may be used. The staple line is straight and about 35 mm long. Special instruments are now available in which the stapling end can articulate up to 45° with the shaft. The disadvantage of the stapling devices to be used in endoscopic surgery is that they require a cannula diameter of 12 mm.

Ligature and Suture

The ability to ligate and to suture tissues in endoscopic surgery is very important. For the ligature of non-continual structures, prefabricated loops with a non-slipping Roeder knot can be used. These prefabricated loops, which are usually made of chromic catgut, are inserted using an applicator for keeping the cannula valve open during insertion and tightening of the loop (Fig. 2.22). To ligate structures that are continuous, the end of the ligature can be inserted through an applicator, put around the particular structure, taken out through the same applicator and

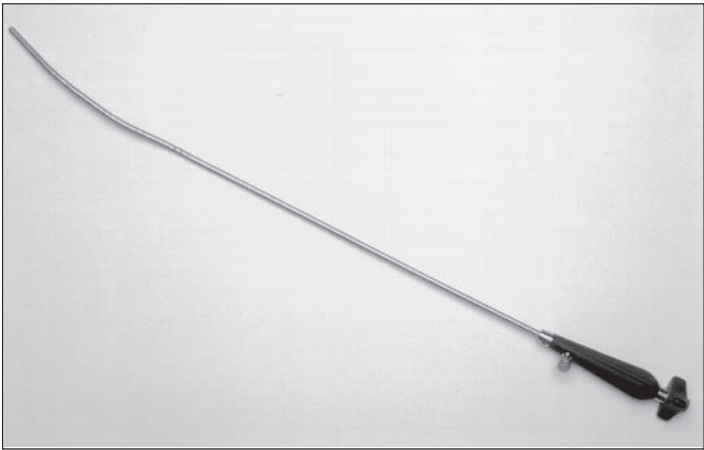


Figure 2.13A. Five mm diameter retractor in its elongated form.



Figure 2.13B. Five mm diameter retractor in its triangular form.

externally knotted after which the knot is pushed in place using a knot pusher (Fig. 2.23). External knotting may be important to tie structures under tension together.

Instead of using partly external techniques, structures can be ligated internally irrespective of whether they are in continuity or not. For internal knotting two instruments are needed in which the opening and closing mechanism of the beak cannot accidentally catch the thread as this interferes with smooth knotting. This means that most grasping instruments in which both halves of the beak move are not suitable for tying. The beak of a needle holder usually has only one half that moves—as an opening and closing mechanism that cannot accidentally catch the thread (Fig. 2.24).

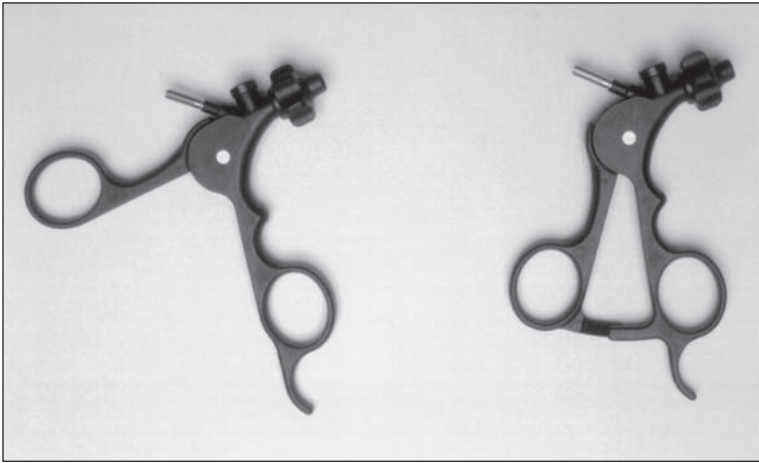


Figure 2.14. Different handles are available. This figure shows a handle that can be locked and one that cannot be locked.

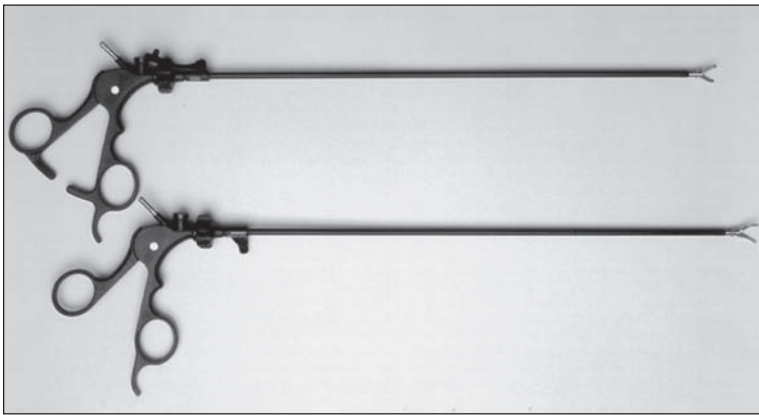


Figure 2.15. Kelly forceps with and without ratchet handle.

There are many needle holders on the market. Again for use in children in whom the manipulation angle is often smaller than 60° it is advantageous to have a needle holder with curved beak so that the tip can be well visualized. For internal tying the pieces of thread to be used should be short, e.g., 10 cm.

For suturing also rather short pieces of thread should be used. A ski-type needle is preferred. The shaft of these ski needles has often an oval diameter which allows for good gripping and prevents turning of the needle in the beak of the needle holder. Both absorbable and non-absorbable sutures are available.

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Figure 2.16. Forceps with broader atraumatic beak for bowel grasping.

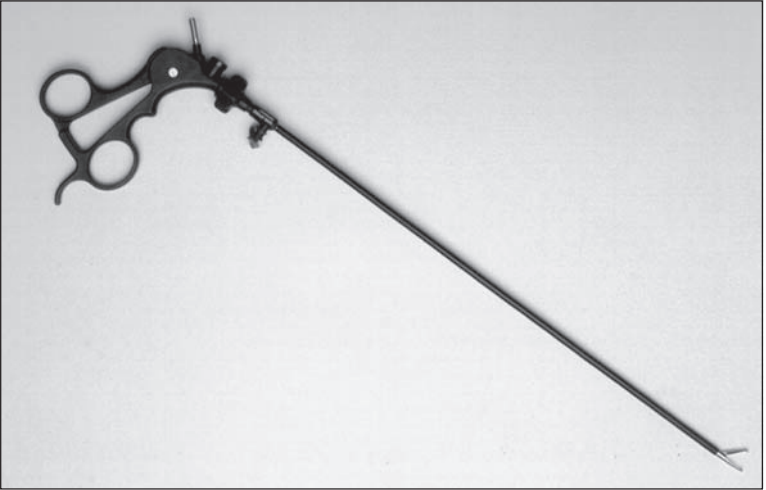


Figure 2.17. Forceps with toothed beak.



Figure 2.18. Hook scissors (upper) and Metzenbaum scissors (lower).

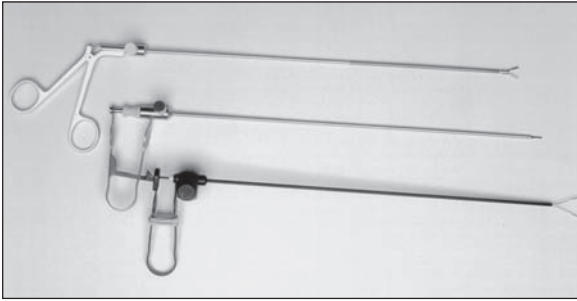


Figure 2.19. Instruments for pyloromyotomy: spreader (upper), knife (middle), and soft bowel clamp (lower). For photographic purposes, the handle of the bowel clamp is kept open by means of a rubber band.

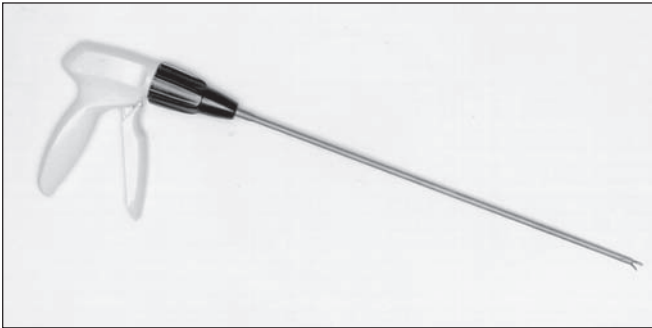


Figure 2.20. Disposable 5 mm diameter clipping device. Two lengths of clips are available.



Figure 2.21. Disposable linear stapler. The newer staplers can be angulated inside the body. The stapler cartridge can be reloaded several times in the same patient. Depending on the thickness of the tissue to be stapled there are two staple sizes. The smaller staplers are used for the sealing of larger vessels.

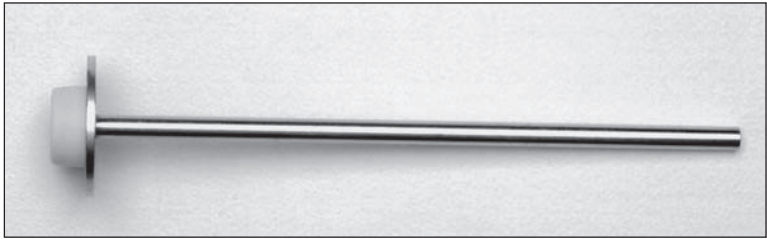


Figure 2.22. Applicator for keeping the cannula valve open during the insertion of sutures or pretied loops.

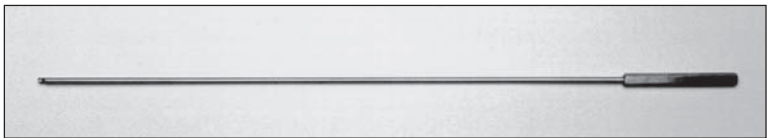


Figure 2.23. Knot pusher.

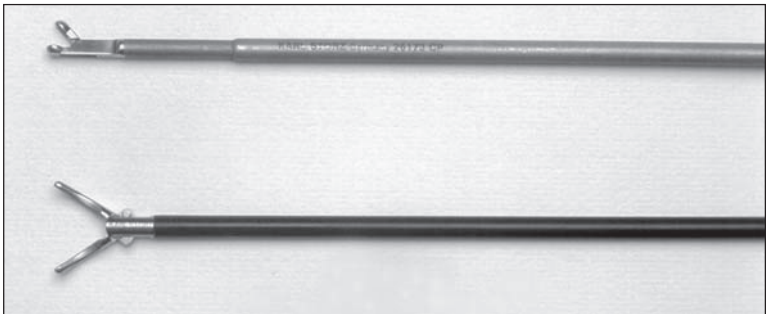


Figure 2.24. Needle holder (upper) and Kelly forceps (lower). Note the difference in articulation of the beak. When both parts of the beak can move, then suture material is likely to be caught in the closing mechanism.

Instruments of Energy Supplying Systems

HFE Coagulation and Dissecting Instruments

Both open and endoscopic surgery require the use of monopolar high frequency electrosurgery (MHFE). The fact that it can be used at the same time for mechanical dissection as well as for MHFE dissection and hemostasis makes it an efficient, multipurpose instrument. Most of these MHFE instruments have a hollow shaft with a valve so that the smoke produced can escape by opening the valve. When a gas at a rather high flow rate is used for the maintenance of the working space, then no suction is required for removal of the smoke as the positive pressure atmosphere will

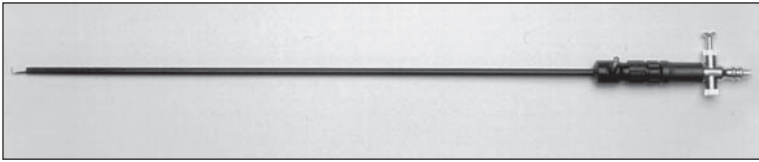


Figure 2.25. Hook for monopolar HFE. Note the valve mechanism at its end allowing smoke to escape.

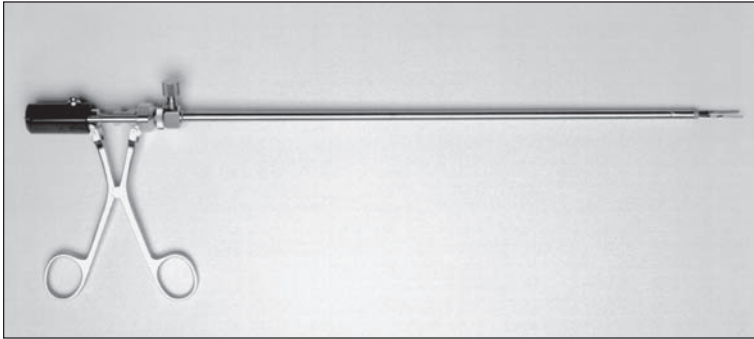


Figure 2.26A. Bipolar HFE instruments. large beak.



Figure 2.26B. Bipolar HFE instruments. small beak.

create a gas current over the opened valve. Alternatively the shaft can be connected to a suction apparatus.

Various monopolar ends are available. The 90° hook end is a good one as it allows for good vision even when the manipulation angle is small (Fig. 2.25). Moreover it allows for dissection underneath vessels. To prevent collateral damage during activation, only small tissue bridges should be taken and coagulated, and the current should be regularly interrupted. Also not too much tension should be exerted as this will cause traction on nerve fibers and may cause distant damage. Traction will result in transection without proper coagulation and may inadvertently damage tissues. While the concave portion of the hook rather coagulates, pressing the convex portion against tissue cuts powerfully. When using the concave portion for coagulation

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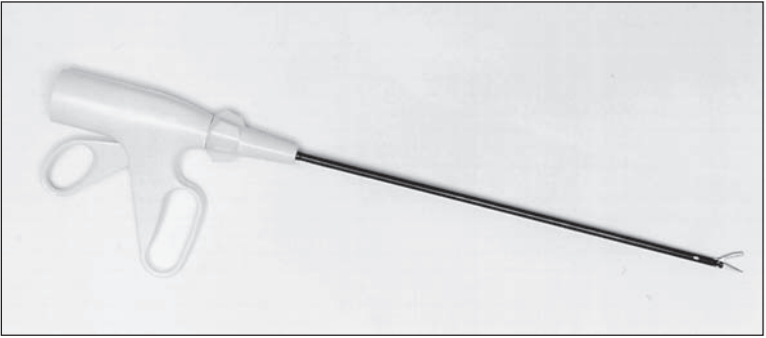


Figure 2.27. Shears for ultrasonic dissection and coagulation. Note the straight beak.

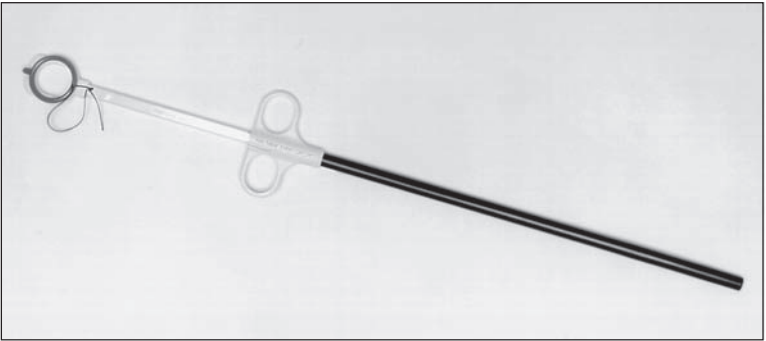


Figure 2.28A. EndoCatch I retrieval bag. Closed device.



Figure 2.28B. EndoCatch I retrieval bag. The device is being opened.

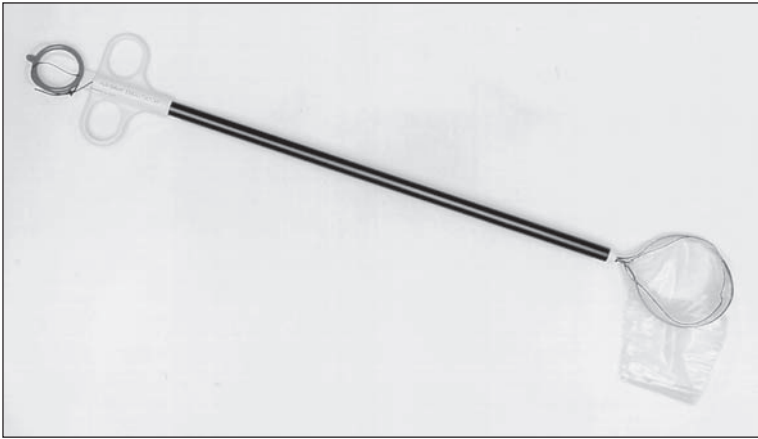


Figure 2.28C. EndoCatch I retrieval bag. The sac is completed opened and ready to accept material.

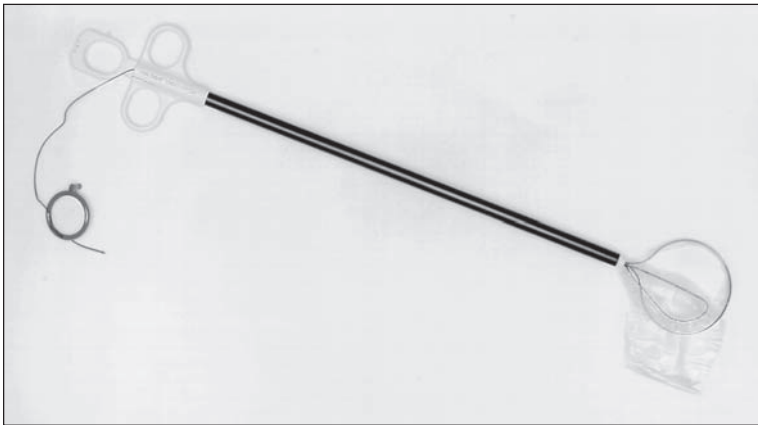


Figure 2.28D. EndoCatch I retrieval bag. The sac is being closed (tearing from the metal ring that kept the sac open).

or cutting, one should be extremely careful for several reasons. Firstly the tissue is pushed away from the telescope instead of being pulled towards it; secondly the convex portion is more difficult to see because it is hidden by the tubular end of the shaft; and lastly more energy seems to be delivered causing faster cutting than expected.

MHFE has the potential hazards of collateral damage caused by insulation failure, inadvertent contact with other metal instruments, or by capacitative coupling. If nondisposable MHFE instruments are used, they should be checked after each operation for insulation failure.

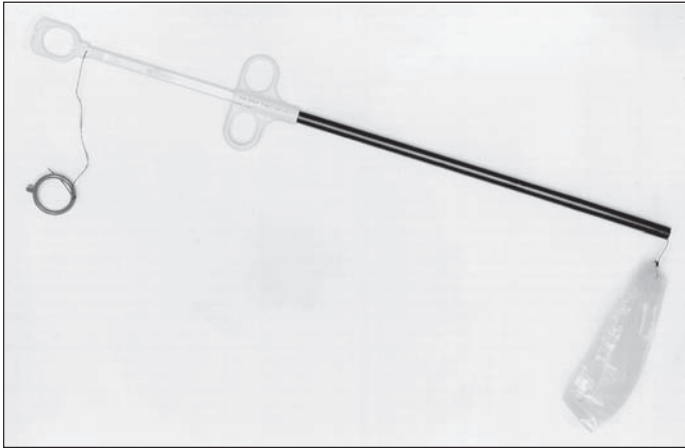


Figure 2.28E. EndoCatch I retrieval bag. The sac is completely closed and ready to be removed (the metal ring has been withdrawn inside the instrument).

Bipolar high frequency electrocautery (BHFE) coagulates between the beak of the instrument and avoids many of the potential hazards of MHFE just mentioned (Fig. 2.26). It has the great disadvantage of being basically a non-cutting instrument, which means that after coagulation another instrument has to be brought in for cutting. Irrespective of whether MHFE or BHFE is used, both modes produce smoke, which not only hampers vision but may also be toxic.

Ultrasonic Dissection/Coagulation Instruments

Ultrasonic energy can be used for sealing vessels and for cutting tissue. The end of the instrument may have different shapes, but the shear is most often used because it can dissect, coagulate, and transect at the same time. For use in children 5 mm diameter shears are available. (Fig. 2.27) Ultrasonic energy avoids the possible hazards of the use of HFE. Moreover it produces steam instead of smoke. Steam causes much less interference with vision than smoke and does not have to be sucked away. In small working spaces however, the steam may blur the end of the telescope. A disadvantage of the shears is that the blades are straight, which makes it difficult to see the tip especially when working in a narrow space, as is often the case in children. One should also keep in mind that ultrasonic energy is energy, and that after longstanding activation a temperature up to 400°C can be generated. As ultrasonic coagulation blanches the tissues, in contrast to HFE coagulation which blackens the tissues, collateral damage may be harder to see. Cooling down of the tip of the instrument takes some time, and immediate contact of the surroundings after deactivation may cause thermal damage. Another disadvantage of the use of ultrasonic energy is the high cost of the shears, which at present are only available in a disposable version.

Removal of Tissue

It is a good principle to take tissues or organs out in a bag thereby preventing spillage or contact with the body wall. Direct contact between infected tissue to be removed and the body wall may result in infection. Rupture of the infected tissue, e.g., an appendix will result in gross contamination of the abdominal cavity. Moreover implantation of cells of the tissue to be removed may occur both in the cavity in which the operation is carried out as well as at the port. This may regard not only malignant cells and result in port site metastasis but also nonmalignant cells for example splenic cells during splenectomy. Rupture of the spleen in the abdomen during extraction will result in splenosis. The sac to be used for extraction should be strong and latex free. Disposable sacs are available in two sizes (Fig. 2.28). These sacs are introduced in a rolled up form. When the whole sac is in the cavity, the sac opens up by means of a spring mechanism. Next the sac is unrolled and the tissue to be removed is placed in the sac. Externally a purse string can be tightened thereby closing the sac and tearing it off the spring mechanism. The device to bring the sac in is then removed and the purse string taken out through the port site. The tissue to be taken out can then be morcelated or alternatively the incision can be enlarged and the tissue in the sac taken out. Electrically driven morcelators are available, but should not be used, as they may easily damage the sac. Improvements in this area are badly needed.

Conclusion

Endoscopic surgery is sophisticated surgery. It relies on good functioning equipment and instruments. It is imperative that the endoscopic surgeon knows what is available, not only on the market but even more importantly in her own operating room. So many different instruments are available that one easily gets lost. The endoscopic surgeon should select a limited number of instruments to compose a standardized set. Without standardization each operation becomes an experiment and this is certainly not in the best interest of the patient.

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Ergonomics in (Pediatric) Endoscopic Surgery

Klaas N.M.A. Bax

Introduction

Ergonomics or “human factors” has been defined as a field that has to do with designing machines that accommodate the limits of the human user,¹ or as the scientific study of people at work in terms of workplace layout, equipment design, the work environment, safety, productivity and training.² Prior to the birth of ergonomics, in World War II, emphasis had been placed on “designing the human to fit the machine”.¹ That is, emphasis was on training. Experience in World War II, however revealed a number of instances in which systems, even with well-trained operators, simply did not work. With increasing technological development in this century, systems have become increasingly complex, forcing the designer to consider the distribution of tasks between the human and machine. In the field of medicine, there has been an increased awareness of the importance of ergonomics and the applications of system analysis. Despite the increasing attention to ergonomics in health care, a recent report by the Food and Drug Administration estimates that poor design of medical instruments may account for half of the 1.3 million unintentional injuries in the US hospitals each year.³

Both the industry and the surgical profession have enthusiastically welcomed the introduction of endoscopic surgery. The industry has developed and marketed video equipment and an extensive range of endoscopic surgical instruments. On their part, surgeons have developed or modified existing techniques, and more recently, instituted measures to audit the benefit, safety and impact of the new endoscopic surgical management. This rapid advancement of endoscopic surgery has encountered and still faces some problems. Most of the endoscopic equipment and instruments in current usage are adaptations from other areas of technology and from open surgery without adequate considerations of the demands of endoscopic surgical techniques. The ergonomic layout of the current operating theatres, designed for conventional open practice, is not ideal for the needs of endoscopic surgery where a variety of high technology ancillary devices are necessary for the conduct of endoscopic interventions. Despite the increasing complexity of these technologies used in the operating theatre, ergonomic progress and design has fallen behind these developments.²

This chapter aims to give an overview of the ergonomic problems associated with endoscopic surgery and of their present time solutions.

Visualization Problems^{2,4}

Endoscopic surgery faces the following visual problems:

Monocular image with loss of depth perception

- Relatively low resolution image
- Video reconstruction of the image
- Magnification of the operative field
- Uncoupling of motor and sensory spaces
- Movement of the camera by the holding assistant
- Variable lighting inside body cavities depending on distance or depending on the amount of blood staining
- 2 or 3D imaging

The lack of depth perception with monocular video systems is a significant performance limitation. Although there are many depth clues present in a classic endoscopic image, stereo disparity is lacking.^{2,4}

The first generation 3 Dimensional systems uses a single lens (or two smaller lenses) endoscope. Apparent binocular disparity on a 2 dimensional monitor is obtained by flickering each image alternately at high frequency (50-60 Hz for each eye). Surgeons are obliged to wear glasses that occlude each eye at the appropriate moment.⁵ Complaints of eye fatigue and headaches have often been expressed and a better performance with the first generation 3-dimensional binocular video systems has been hard to prove.⁶

A second generation system addresses the problems of flicker, distortion, and the conflict between mismatched depth clues. The 10 mm diameter endoscope uses a proprietary optical design with two points of view spaced 4 mm apart.⁵ The working distance can vary considerably while maintaining a comfortable stereo image. A special monitor contains two images, which can only be seen by one eye each. There is a glass free version in which the monitor adjusts the images according to the observer's location and a version without this facility. In the latter case, the image is polarised differently for each eye and the observer has to wear passive glasses. With this 3-dimensional system the endoscopic handicap is reduced by about 50%. Whether it will be possible to make such an endoscope with a diameter of 5 mm or less for use in small children remains uncertain at present.

Position of the Image

Task performance is better with frontal view direction: execution time is shorter and performance score is higher than with side viewing, with no significant difference between right and left viewing directions. (Fig. 3.1) With frontal direction, hand-level gaze down viewing results in a shorter execution time and a higher performance score than eye level viewing.⁷ Despite this research, most monitors are still placed on a rather high tower. Apart from a lesser task performance, high placed monitors may result in complaints of neck stiffness and pain. Mounting the screens on adjustable ceiling arms is expensive and does not really solve this problem, as the screens cannot come far enough down.

Most endoscopic surgeons use 50 cm screens, yet the amount of information conveyed is related to the number of pixels and not the size of the screen. Closer positioning of a smaller 2D image nearer to the subject's eyes resulted in a significant benefit to the novice subjects.⁵ Small screens mounted on glasses in front of the eyes may be the solution, as the relation between eyes and screen become fixed. The present system however is not of sufficient quality.

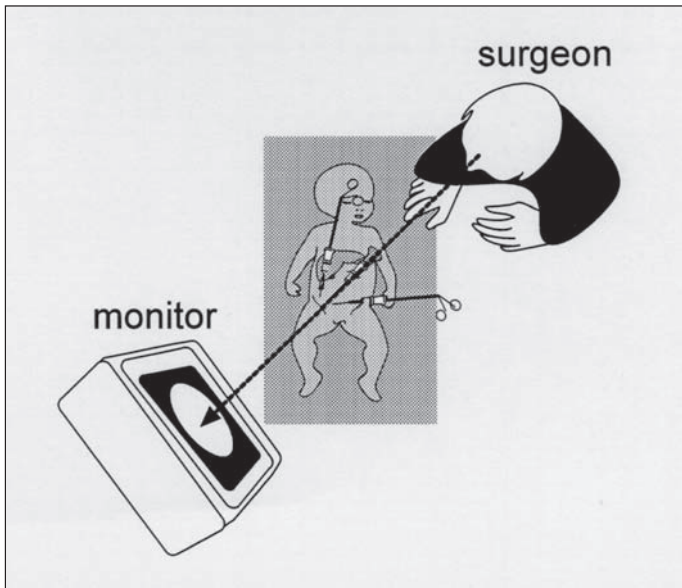


Figure 3.1. Surgeon, target and monitor are in line. The best task performance is obtained with the monitor located in front of the operator, with an axis of view of 25-30° below the horizontal. (Reprinted with permission from Waldsmid t J, Bax NMA. Diagnostic laparoscopy, In Bax NMA, Georgeson KE, Najmaldin A, et al. eds: Endoscopic Surgery in Children. Berlin, Springer Verlag, 1999; 137-154).

Projection of the video image on a white plate, that is put in the vicinity of the region to be operated, is another possibility and is already on the market (ViewSite display system, Storz, Tutlingen, Germany). Task performance seems to be improved considerably but the present system has a number of drawbacks: The quality of the projected image is less than the quality of the image on a classic monitor. Moreover as the image is projected, any additional light decreases the imaging quality.

Lightweight sterile flat screens that can be put on the patient are being produced, and have a number of theoretical advantages, e.g., easy suspension and position adjustment.

Auxiliary screens are important for operating room personnel to follow the operation, e.g., anesthesiologist and scrub nurse. However, for the assistant and cameraperson, the same ergonomic laws as for the surgeon apply, which means in line position of the surgeon, scope, operative field and monitor. If classic screens are used then a second screen on the other site of the patient is mandatory when the site of the operative field changes during the operation, e.g., during a subtotal or total colectomy.

Stability of the Image

When a cameraperson is used to hold the camera, no real stable image is obtained. Depending on the skills of the cameraperson, his motivation, and the length of the procedure, more or less movement of the camera occurs. This can impede the surgeon's performance, causes motion sickness, and increase the surgeon's irritability. A well-functioning voice-controlled robotic arm is on the market.⁸ Disadvantages at the time being are the high cost and the heavy weight of the robot. As personnel is the most expensive factor in running operating rooms, systematic use of the robot may be cost effective when the load of endoscopic surgery is high enough.

Choice of the Endoscope

The best task performance during endoscopic work is obtained with an optical axis to target view (OATV) angle of 90° and relatively small decreases in this viewing angle are attended by a significant degradation of task performance. (Fig. 3.2) The error rate increases from 17% with an OATV angle of 90° to 79% with a 45° angle. In addition a significant increase in the execution time and the force applied on the target with the decrease in the OATV angle is observed.⁹ In practice only oblique viewing endoscopes or ones with a flexible tip can achieve and maintain an adequate OATV angle approximating 90°. In addition, the visual field changes when the forward oblique scope is rotated whereas the operative field of forward viewing scopes is unaltered. As the physical axis of angled scopes differs from the optical axis and does not converge to the target, entanglement of the scope with working instruments, which axes do converge on the target, is less likely to occur. For advanced endoscopic surgical procedures, the use of angled scopes is a must. Scopes with an angle of 30° are most popular.

In order to obtain an OATV angle of about 90°, the optical port location should be carefully selected.

Although the quality of smaller scopes steadily improves, the smaller the diameter the poorer the image and the illumination. Scopes with a diameter of 5 mm are sufficient for most operations. In small babies a 3 mm scope may be sufficient.

Hemostasis

As blood absorbs light, bleeding should be avoided, and if it does occur it should be stopped immediately and the clots should be removed.

Fogging and Blood Staining of the Tip of the Scope

Fogging or blood staining of the tip of the scope is a major problem in endoscopic surgery. Initial fogging due to coldness of the scope may be avoided by preheating the scope in a thermos flask with hot water. Later fogging caused by the insufflation of unheated CO₂ can be avoided by changing the CO₂ insufflation to a port other than the optical port or of course by preheating the CO₂. Wiping of the tip of the scope against surrounding tissue is not advisable as the tip of the scope reaches 95° Celsius after 15 minutes.¹⁰ This may not only damage the surrounding tissue, but also will cause adherence of coagulated tissue and hamper vision further. Removal of the scope, cleaning in hot water in a thermos flask, and reintroduction is the best solution for the time being. For drying, each time a new swab should be used as the slightest contamination of the swab with blood will also contaminate the

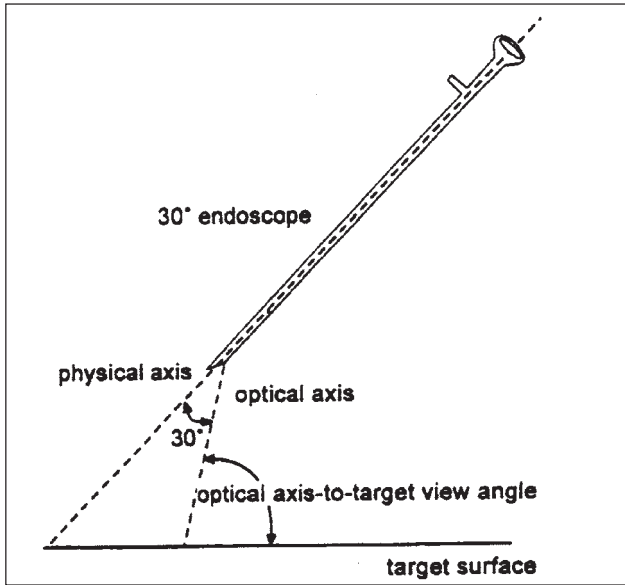


Figure 3.2. An optical axis to target view of about 90° is ideal. This is easier to achieve with a 30° telescope. (Reprinted with permission from Hanna GB, Kimber C, Cushieri A. Ergonomics of task performance, In Bax NMA, Georgeson KE, Najmaldin A, et al eds: Endoscopic Surgery in Children. Berlin, Springer Verlag, 1999; 35-48).

tip of the hot scope. Agents that prevent fogging are also available. Each time that the scope has to be cleaned, not only time is lost but also at the same time there is no image of the operative field and inserted instruments may cause inadvertent damage.

Manipulation Problems^{2,4}

- Limited number of degrees of freedom
- Diminished tactile feeling
- Increased resistance to manipulation
- Small and long instruments
- Problems of tissue retrieval

Degrees of freedom, diminished tactile feeling, resistance to manipulation

Standard endoscopic surgical instruments have only four degrees of freedom. The instrument can be moved in and out along the Z axis, it can be rotated in the line of the Z axis, it can be moved side-to-side on a point on the Y axis, and it can be moved up and down about the X axis. Moreover the instruments move through cannulae which have to be air tight when CO₂ is used for the creation and maintenance of the working space. This resistance results not only in diminished tactile feeling but also in more force to be used. In gasless endoscopic surgery, there is no need for a tight fit. As a result tactile feeling is preserved better, and less force has to be used.

The mechanical design of endoscopic instruments results in diminished tactile feeling and in increased force to be used. Endoscopic instruments require 4 to 6 times more force than open surgery instruments to complete the same task.⁴ Moreover much higher forces are needed when the surgeon is working at 90°. The handling of the current generation of laparoscopic instruments during grasping motions entails flexion and ulnar deviation of the wrist, which decrease maximum grip force. It has been shown that the use of laparoscopic instruments results in greater forearm discomfort, possibly due to the need for increased forearm flexor muscle contractions compared to conventional surgical instruments.¹¹ The handle configuration of laparoscopic instruments requires the operator to use the opposing muscles of the thenar and hypothenar compartments for gripping rather than the more powerful grasping grip that uses the deep forearm flexors. That instruments are not optimal yet is highlighted by publications on the occurrence of thumb paresthesia, associated with laparoscopic surgery.^{12,13} An in-line configuration of the instruments, however, seems not advantageous above a pistol-grip.¹⁴ Alternative instrument handles have been designed but no ergonomic data are available to support their superiority.

Port Placement

A combination of 60° manipulation angle with 60° elevation angle has the shortest execution time and highest performance quality score.¹⁵ Moreover the azimuth angles should be equal. (Fig. 3.3) This means that for each endoscopic operation, the surgeon should make a plan as to the exact location of the various ports to be inserted. Factors such as the size of the person to be operated and the target area to be reached as well as the length of the available instruments should be taken into account.

Size of the Instruments

The diameter of the instruments is dictated by the size of the cannulae. The length of the instruments should depend on the size of the patient and the operative site. Based on research a ratio between the intra- and extracorporeal shaft length of two to one has been found to result in optimal task performance.² Whether this also holds true when operating in small working spaces remains to be proven but seems unrealistic. In any case long thin instruments have a poor mechanical advantage. Moreover the narrow end of thin instruments may cause accidental perforation or tissue damage during gripping.

The length of the cannulae should depend on the size of the patient. In view of the limited size of the working spaces in children only a small part of the cannula should enter the cavity to be operated. However this causes problems of cannula fixation. If the cannula is not fixed to the fascia but only to the skin, distraction of the skin from the underlying fascia may dislodge the cannula. See also the chapter on "Instrumentation".

Problems of Tissue Retrieval

Tissue to be removed should fit the largest cannula used. This means that when the tissue to be removed is larger, the tissue has to be diminished in size or that the access has to be widened. See also the chapter on "Instrumentation".

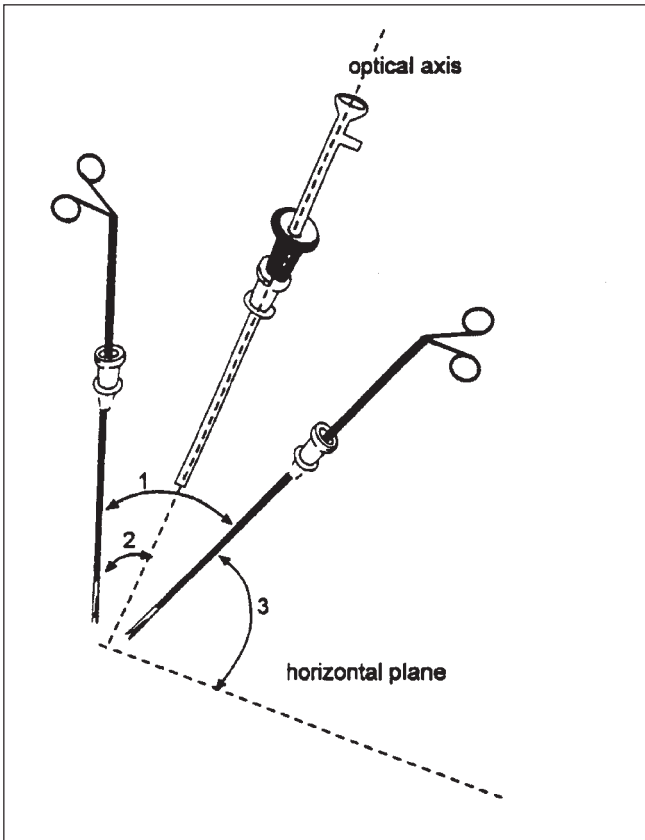


Figure 3.3. Angles govern port placement. Optimal angles are: 1 manipulation angle: 45-75°; 2 azimuth angle: equal; 3 elevation angle: 60°. (Reprinted with permission from Hanna GB, Kimber C, Cushieri A. Ergonomics of task performance, In Bax NMA, Georgeson KE, Najmaldin A et al. eds: Endoscopic Surgery in Children. Berlin, Springer Verlag, 1999; 35-48).

Posture Problems

- Standing position
- Long duration

The relationship between fatigue and disability on the one hand and static as well as dynamic postural stress has been recognised for a long time in industrial ergonomics.⁴

During surgery in a standing position, surgeons and scrub nurses experience substantial stress to the musculoskeletal system owing to frequent and prolonged head-bent and back-bent postures.⁴ During laparoscopic procedures 70% of the intraoperative work postures are substantially static.⁴ Compared with standing open

surgery, standing endoscopic surgeons operate in a more upright position and with much less body movement and weight shifting.¹⁶ Moreover as most energy supplying systems are operated by foot, the standing endoscopic surgeon basically stands on one leg for most of the procedure. Special positions may result in special problems, e.g., operating from the side of the patient results in muscle fatigue in the shoulder region.²

Sitting instead of standing is more restful and provides a more stable posture for controlling instruments during microsurgery.⁴ No comparative studies between standing and sitting surgery are available yet. As far as stability of the instruments is concerned, there is a big difference with microsurgery as the ports in endoscopic surgery stabilise the instrument. Nevertheless operating in a sitting position will cause less static fatigue. Moreover a sitting position will allow for a better control of the energy supplying systems. In fact in a sitting position both feet are available for operational use.

The postural problems are compounded by the often long duration of endoscopic procedures.

Mental and Physical Workload

The surgeon has to reconstruct a 3D picture from a 2D image and to perform the task under several mechanical and visual restrictions.^{2,4} Moreover he often stands for a long time in a more or less upright position and with less mobility of the head and neck and less anteroposterior weight shifting than during open surgery. The physical, mental and visual demands of endoscopic manipulations may be responsible for surgical fatigue syndrome encountered in endoscopic surgery. After a variable but finite time, the surgical fatigue syndrome sets in, manifested by mental exhaustion, increased irritability, impaired surgical judgement and reduced level of psychomotor performance.²

Operating Room Environment

To put facts found out by research in the field of ergonomics into practice, operating rooms have to be adjusted. This is a problem in view of the rapid changes in technology and the high costs of operating room adjustments. Nevertheless the basic ergonomic principles should be respected. In discussions about ergonomic layout of operating rooms for endoscopic surgery the operating table is often not mentioned. The operating table should be very versatile allowing for all possible positions. At the same time the patient should be securely strapped to the table in order to prevent accidental falling off. The height of the table should be adjusted to allow for comfortable manipulation. The shoulders should be in a neutral position. Operating with pulled-up shoulders is tiring and causes neck pain. The forearms should be in 90° extension or slightly more. The surgeon should also take into account that the assistant more often than not will not be of the same height. Footboards of different heights are of help in this respect. Most footboards however are rather small and do not have enough room to accommodate the foot pedals of all energy supplying systems. Operating in a sitting position should be further explored. Completely adjustable chairs with specially designed footboards to accommodate the pedals of the energy supplying systems may prove to be a great advantage. While guidelines for an optimal position behind a computer desk are available for a long time,

such guidelines for the endoscopic surgical crew are missing but badly needed (Fig. 3.4).

Not enough attention has been paid to the control of the energy supplying systems by foot. Often there is foot pedal for monopolar and one for bipolar electric energy, and a double foot pedal for slower coagulating and cutting ultrasonic energy. All foot pedals should be fixed on a template in a certain order. Imagine how dangerous it would be if the foot pedals of cars would not always be in the same position!

3

The position of the dominant screen should also be very versatile, allowing all the time for an inline position of surgeon, target, and screen. Now that the large heavy screens are being replaced with smaller lightweight flat screens, mounting of these newer screens on a versatile sealing arm is less expensive.

The most often used actual set-up is a tower with the screen on top of it and with the camera control unit, the light source unit, the insufflator and the video recorder below the screen. This set-up has several drawbacks. The height of the screen is not adjustable and when the screen has to be moved in a horizontal plane, the whole tower with all connecting cable has to be moved. A major improvement is obtained by spatial uncoupling of the screen from the remaining parts of the tower. The position of the screen should be easily movable while the remaining part of the tower can remain in a relatively fixed position, e.g., behind the back of the surgeon.

The many cables in endoscopic surgery are also a problem. All together 8 or 9 cables enter the operating field. It would be nice if all these cable could come from a versatile ceiling-mounted arm.

Overall Control of the System

One of the major problems associated with sophisticated technology is the control of the system. In aviation, function and safety of the airplanes are checked all the time. Airplanes have many automatic system checks, but each time before departure the pilots have a list of items to check themselves. Not only the is machine tested regularly, but the pilots also use sophisticated airplane simulators.

In endoscopic surgery, things should be not different, but at the time being, this has certainly not been realized.

Before starting, the surgeon should check the system:

- Availability
- Video equipment
- Scopes (diameter, angulation)
- Light source/cable
- Insufflator/ CO₂
- Endoscopic instruments
- Nondisposable instruments
- Disposable instruments
- Conventional instruments
- Energy supplying systems
- Function
- Video equipment
- Screen (settings)
- Light source (settings)

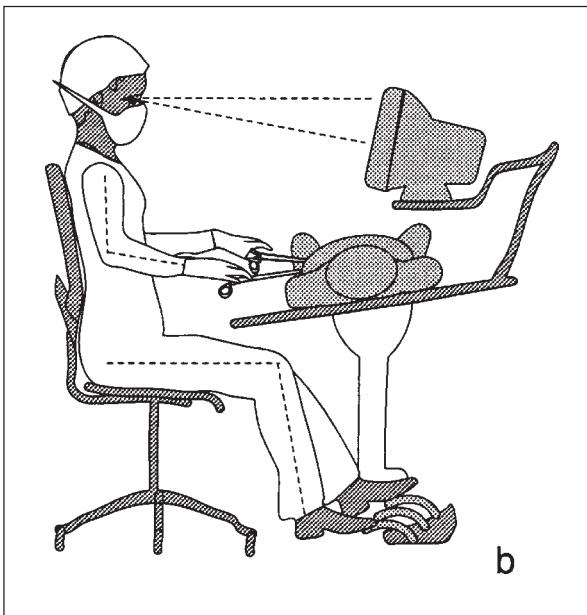
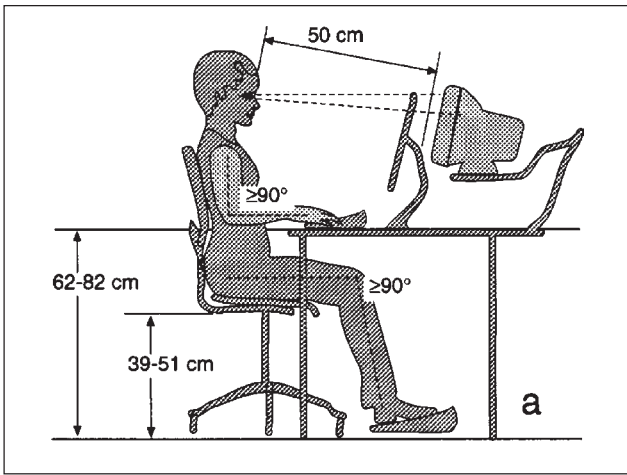
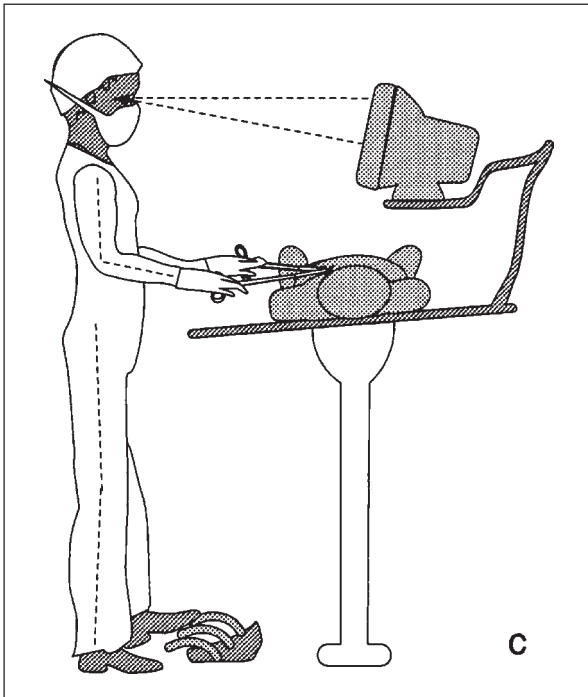


Figure 3.4 a-c. Guidelines for work place layout: a) work in a sitting position behind a computer desk; b) endoscopic surgery in a sitting position: In a sitting position, both feet are available for the command of energy supplying or other systems; c) endoscopic surgery in a standing position. Only one foot at the time is available for the command of systems.



- Light cable (compatibility with scope)
- Scope
- Camera
 - white balancing
 - enhancement
- Videorecorder (setting, tape loaded, tape running)
- Insufflator (settings)
- Suction/irrigation (settings)
- Energy supplying systems (settings, foot pedals)
- Positioning
- Patient
- Crew
- Table
- Screen
- Foot pedals

This list is not exhaustive. Technology can assist in making this check easy and quick. By turning on the power of the video equipment, the screen could give a menu of items to be checked and failure to do so would result in a non-functioning system. Perhaps depending on the age of the patient, the type of operation to be performed and preferences of the surgeon a number of settings are expressed automatically.

Adjustments of settings should be possible using a voice-controlled system but settings should be projected on the screen at the same time.

Training

There is little doubt that more attention has to be paid to the selection of future surgeons. Much the same as in aviation, surgeons should be selected as is done with aviation pilots. Increasingly task performance is tested. This can be done by using simple standardized tests looking at parameters such as execution time. Meanwhile psychomotor testers have been developed, of which some allow very detailed studies.¹⁷ These tests evaluate improvements in endoscopic surgical skills with training. As might be expected, it has now been proven that hands-on training in laparoscopic surgery improves performance.^{18,19} It has also become clear however that not everything can be improved with practice. Hanna et al, in a study comparing the endoscopic surgical abilities of right and left handed individuals, found a significant difference in the error rate and first time accuracy between subjects, and between the dominant and non-dominant hands.²⁰ No significant change occurred with practice. Right-handed subjects performed better with either hand in terms of error rate and first time accuracy. Practice improved the execution time and the degree of angular deviations. Such studies have important implications and it leaves little doubt that this type of research will be implicated in the future to test future surgeons regarding their innate abilities.

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Laparoscopic Pyloromyotomy

Rajeev Prasad

Introduction

Infantile hypertrophic pyloric stenosis (IHPS) is a common cause of gastric outlet obstruction in infants and presents as one of the most common surgical conditions of infancy.¹ It is an acquired disorder of unknown etiology in which hypertrophy of the muscle fibers of the pylorus occurs, causing a mechanical obstruction of the gastric outlet along with associated metabolic and electrolyte disorders. This condition has been successfully treated for decades with the open Ramstedt extramucosal pyloromyotomy, which clearly stands as the gold-standard treatment against which all other techniques must be compared.² So highly effective is this simple, elegant, and inexpensive operation that it has been described as “one of the most easy and gratifying procedures performed by pediatric surgeons”³ and “the most consistently successful operation ever described.”⁴ Despite the success and popularity of the Ramstedt pyloromyotomy, complications occasionally do occur including prolonged post-operative emesis, wound infection, and duodenal perforation. In addition, there is a permanent scar which may negatively impact on the self image of some children. To deal with the issue of cosmesis some surgeons have advocated a circumumbilical incision for pyloromyotomy.⁵ However, it appears that this approach, although an acceptable alternative to Ramstedt’s technique, has its own shortcomings including infection, incisional hernia, and prolonged gastroparesis. The laparoscopic approach to pyloromyotomy obviates many of these concerns. There is clearly an advantage as far as cosmesis is concerned and the anticipated increased complication rate and costs have not consistently been demonstrated. The technique has evolved over the last decade and appears to be at the very least an acceptable alternative to the time-honored open approach.

Historical Perspective

Gans and Berci may perhaps be considered the ones who set the stage for laparoscopic pyloromyotomy in the 1970s when they stated that “peritoneoscopy in infants and children provides a clear view of the peritoneal cavity and offers a satisfactory means of biopsy and other manipulations under direct vision.”⁶ More recently with the increased interest and experience among pediatric surgeons over the last decade as well as the increased availability of miniaturized instrumentation, laparoscopy in general has become an essential part of the modern pediatric surgical armamentarium. However, the application of laparoscopy to the treatment of IHPS occurred late as compared to other procedures such as cholecystectomy and fundoplication, as it was difficult to justify any attempt to improve on the open technique. Issues such as the added costs and the risks of bleeding and perforation

initially outweighed the benefits of improved cosmesis and a potential for a slight improvement in an already short operative time and recovery.

Despite this some surgeons forged ahead and established the basis upon which others have improved. Alain et al reported their initial experience in 10 patients in 1991.⁷ In the first two infants the effectiveness of the laparoscopic procedure was in fact confirmed by an open abdominal incision without exteriorizing the pylorus itself. All of the patients had an uncomplicated postoperative course, and so the authors were the first to conclude that laparoscopic pyloromyotomy was a sound and technically simple procedure. Tan and Najmaldin reported their initial experience in 1993.⁸ They improved on Alain's technique in that they were able to perform the procedure with one assistant rather than two and their patients were discharged sooner than those in the earlier series. Two years later the same authors reported a series of 37 patients, all of whom underwent laparoscopic pyloromyotomy. They documented the average time of operation (29 minutes), the average time before the initiation of feedings (5.2 hours), and the average time to discharge (28 hours).⁹ Furthermore they had no technical failures. In 1995 Castañón et al described the pyloric traumamyoplasty, an entirely new approach to splitting the hypertrophied pylorus.¹⁰ In this technique two crushing applications of a laparoscopic Babcock clamp were used to rupture the pyloric muscle, thus creating two grooves in the muscle and relieving the obstruction.

The further evolution of laparoscopic pyloromyotomy beyond the work of these pioneering individuals has been evident, as several more authors have more recently described their results as well as technical improvements in the procedure. Rothenberg described his slice and pull technique in 1997.¹ In this procedure the duodenum is grasped with a laparoscopic Babcock clamp, and a sheathed arthroscopy blade is used to perform the myotomy. All 20 patients in this series had an uncomplicated postoperative course. The average operating time was 13 minutes, and 19 of the 20 patients were discharged in less than 24 hours. Importantly, he also demonstrated the cost effectiveness of the laparoscopic approach as versatile, reusable instruments were used excepting the inexpensive, disposable blade. Bufo et al described a safer technique in which the stomach rather than the duodenum is grasped and the pyloromyotomy completed from the right with a retractable arthroscopy blade and a laparoscopic pyloric spreader, with grooves on the outside of the clamp.¹¹ Harris and Cywes presented a simple technique in which the only required instruments were an extended-tip cautery device and two reusable, laparoscopic pyloric spreaders.¹² In their hands the cost of laparoscopic pyloromyotomy was actually less than that for the open technique.

Details of the Operation

Preoperative Preparation

The diagnosis of pyloric stenosis is made in most instances by history and by the presence of a visible gastric wave as well as palpation of the pyloric tumor. If no "olive" is palpable, ultrasonography or, occasionally, a contrast upper gastrointestinal series makes the diagnosis. Just as for the open technique, each patient must be hydrated before operation and the electrolyte and metabolic derangements are corrected. If the patient presents with abnormal laboratory values (low chloride, low potassium, elevated bicarbonate, and/or elevated urine specific gravity) one should

institute aggressive fluid therapy. This consists of normal saline boluses until urine output is established. Five percent dextrose in normal saline + 30 meq potassium chloride per liter at 1.5 times the maintenance rate is used thereafter. An intravenous H₂ blocker is started as a significant gastritis, with the potential for bleeding, may be present. Once the laboratory values are corrected and the patient is properly resuscitated, informed consent is obtained and the operation is scheduled.

Intraoperative Technique

After the induction of anesthesia the patient is positioned in the normal length-wise orientation on the operating table just as for an open pyloromyotomy. The bladder is emptied using a Credé maneuver. Special attention is given to cleansing the umbilicus and the abdomen is prepped and draped in a standard fashion. Prophylactic antibiotics is administered to minimize the risk of postoperative wound infection. The operating surgeon stands on the patient's right and the assistant stands on the left. Notably no suction cannula or electrocautery device is opened. A stab incision is made in an infraumbilical skin crease or in the base of the umbilicus. Through this a Veress needle is placed and the abdomen insufflated to approximately 12 mmHg. A 2 mm needle port is then placed through which a 1.7 mm, 0° telescope is introduced. A general abdominal inspection is performed, confirming the presence of the hypertrophied pylorus. A tiny skin incision is made in the left upper quadrant to the left of the midclavicular line, half way between the umbilicus and the costal margin. Through this a 2 mm Mini port is introduced for passage of an atraumatic grasper and the gastric antrum, just proximal to the pylorus, is grasped. A mirror image stab incision is made in the right upper quadrant. Through this, a retractable arthroscopy knife is passed directly (without using a laparoscopic port). With the blade extended, the pylorus is incised in an area of relative avascularity from the antrum to just proximal to the duodenal bulb. The pyloric incision is bluntly deepened with the blade retracted, as would be done with the back of a knife handle. The arthroscopy knife is then removed and a laparoscopic pyloric spreader is introduced. The pyloromyotomy is then slowly and steadily widened under direct vision until the pyloric ring is adequately split. This is confirmed by grasping the edges of the split muscle (one edge with the grasper and the other with the pyloric spreader, both instruments already being in the abdomen) and moving them independently of one another. The minor bleeding that may have occurred has usually stopped by this point. An essential step at this point is to examine the pyloromyotomy site for perforation. The stomach is insufflated by the anesthesiologist with at least 60 cc of air via a nasogastric tube, and any sign of air bubbles or extravasation of bilious fluid is carefully sought. Once the absence of a perforation is confirmed the instruments are removed and the abdomen is allowed to desufflate. Steristrips are all that are required for closure in this sutureless technique.¹³

Postoperative Management

The patient is returned to a regular floor bed and intravenous fluids, consisting of 5% dextrose in normal saline with 20 meq potassium chloride per liter at a maintenance rate, are continued. Four hours postoperatively the patient is examined for signs of peritonitis (which if present would most likely be due to an unrecognized intraoperative duodenal perforation). If all is well feedings are initiated. One ounce

of formula or breast milk is initially offered. Feedings are advanced every 2 to 3 hours (by 1 ounce if formula feeding or 3 minutes if breast feeding) eventually to ad libitum feeds. All parents should be given detailed instructions regarding proper positioning of the infant during and in between feeds, frequent burping during each feeding, and to resume feeds at the same volume after 3 hours should any emesis occur, thus avoiding any setbacks. If more than two episodes of emesis do occur, the stomach is gently lavaged with a dilute sodium bicarbonate solution via a nasogastric tube before refeeding. This is highly effective in treating the gastritis that may have been present before operation. The infant is discharged once tolerating ad libitum feeds.

4

Outcome

As already stated, the Ramstedt open extramucosal pyloromyotomy is the gold-standard technique for the treatment of IHPS. It is a quick, simple, safe, and inexpensive operation associated with a rapid postoperative recovery. For literally decades it had been considered unnecessary to attempt to improve on such a highly successful operation. However, there are known complications of the open technique. Wound complications including infection, incisional hernia, and frank dehiscence are possible. In addition, postoperative emesis due to gastric atony may be a direct result of the traction necessary to deliver the pylorus through the abdominal incision. The cosmetic result may be poor, and this may affect the psyche of an older child to the point that they may wish scar revision or removal. The circumumbilical approach to open pyloromyotomy addresses the cosmetic issue, but this incision also is associated with infection, dehiscence, and hernia.⁵ Furthermore the degree of gastric manipulation and the degree of difficulty of the operation are increased.

The advent of laparoscopy and its increased application in pediatric surgery necessitated a reevaluation of the surgical options for the treatment of IHPS. Arguments against a laparoscopic approach claim that there are the increased risks of perforation and bleeding, that at best there are no differences in outcome or length of stay, and that the operative and hospital costs are increased. However, the learning curve for laparoscopic pyloromyotomy is not extreme and with increased experience and refinements in technique many of the potential disadvantages have been disproved.

Few would argue that the cosmetic result is superior with the laparoscopic approach as compared to the traditional right upper quadrant incision. There are the theoretical advantages of a more rapid recovery, less postoperative pain, and fewer postoperative adhesions, as is the case with other laparoscopic procedures. There appear to be fewer wound complications (infection, hernia, and dehiscence) as evidenced by the paucity of reports in the literature of such events. There may be less gastric atony due to the fact that it is unnecessary to apply as much traction to the stomach. Greason et al aptly stated that infants treated with laparoscopic pyloromyotomy appear to return to normal feedings as rapidly as do those treated with the open method, that the incidence of postoperative emesis is similar for the two groups, and that these results have been achieved without an increase in the procedure-associated morbidity rate.¹⁴ Furthermore the procedure can be completed expeditiously,^{3,9,11-13} and, with the proper selection of instruments, it may be performed with less expense.¹² In a direct, retrospective comparison between open versus

laparoscopic pyloromyotomy, Scorpio et al demonstrated that there was a significantly shorter hospital stay in the laparoscopically treated group.¹⁴ Notably, there were similar operative times and complication rates in the two groups.

Despite the growing popularity and success of laparoscopic pyloromyotomy, areas for improvement do exist. For instance one would expect the expense of instrumentation to decrease, further improving the cost effectiveness of the technique. Inadequate pyloromyotomy is a pitfall that exists, especially for the less-experienced pediatric laparoscopist who may not be accustomed to the magnified view of the pyloric tumor. There will always exist the potential for bleeding, perforation, and wound complications but with further experience these should become rarer. Thus the disadvantages of the laparoscopic approach proposed in the past can currently be considered to be only relative disadvantages, depending on the level of experience and the technique employed by the pediatric surgeon today.

Laparoscopic pyloromyotomy appears at the very least to be equally as safe and as effective as the open approach and should be considered an excellent alternative technique, especially for the experienced laparoscopic surgeon. Perhaps in the future, following its application to a larger group of patients and after further advancements in instrumentation, laparoscopic pyloromyotomy may prove to be the preferred method in the management of IHPS.

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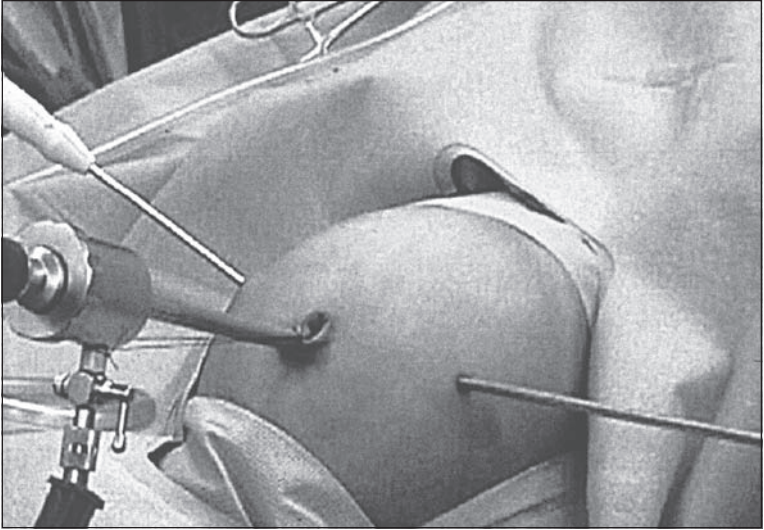


Figure 4.1. Basic set-up for laparoscopic pyloromyotomy with peri-umbilical trocar for the telescope, a right upper quadrant stab wound for the disposable arthroscopy blade and the pyloric spreader, and a left upper quadrant stab wound for the grasper.

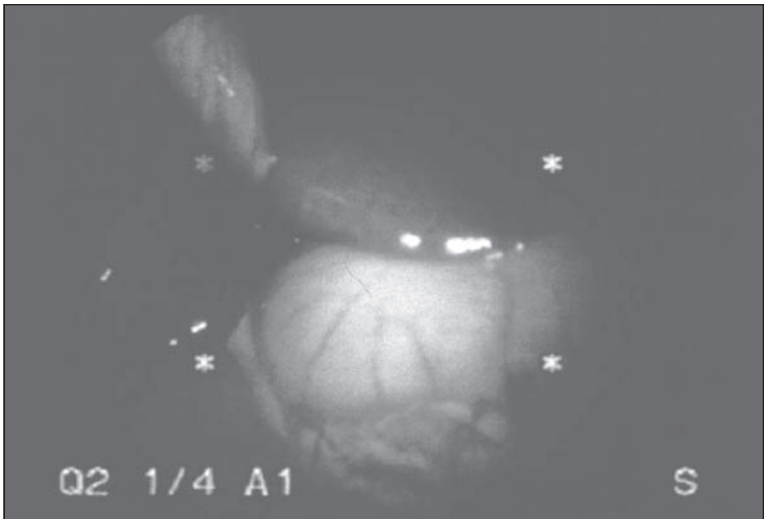


Figure 4.2. Laparoscopic view of the pyloric tumor.

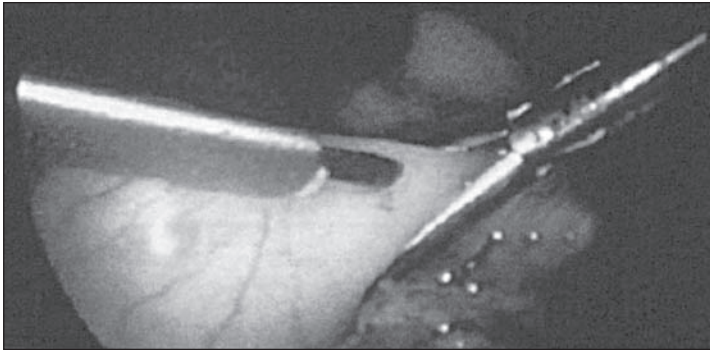


Figure 4.3. Incising the pyloric tumor with the extended arthroscopy blade.

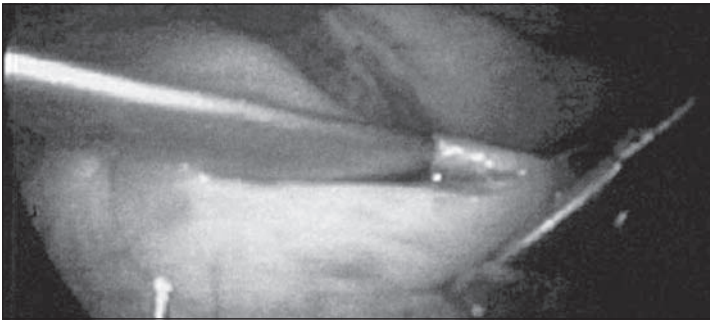


Figure 4.4. Splitting the tumor with the sheath of the retractable arthroscopy blade.

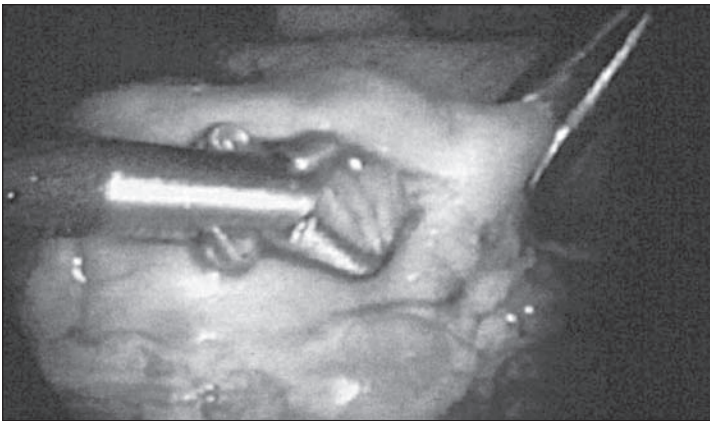


Figure 4.5. Spreading the pyloric muscle with the pyloric spreader.

The Use of Robotics in Minimally Invasive Surgery

Martin L. Blakely and Holly L. Neville

Introduction

With the recent explosion in techniques available to the pediatric surgeon, minimally invasive surgery has made great strides in its clinical applicability. Many minimally invasive surgeries, including both laparoscopic and thoracoscopic techniques, are now performed on a routine basis. An emerging technology, which will facilitate advancement of minimally invasive surgery, is the use of robotics. The most frequently used surgical robot is AESOP[®] (Computer Motion, Santa Barbara, CA). The use of AESOP[®] allows optimal positioning and control over the telescoping camera, which we feel is most beneficial in minimally invasive surgery for children and infants (Fig. 5.1). Due to the small size of these patients, increased precision is needed during operation. AESOP[®] allows the operating surgeon to control the laparoscope or thoracoscope as opposed to the assistant. By using voice-activated technology, the AESOP[®] robot maneuvers the telescope very precisely, allowing the operative surgeon to have more control over the operative procedure.

There are other robotic instruments currently being developed, which will not only control the telescope and camera, but will also provide control over the instruments involved during the procedure as well. Computer Motion is developing ZEUS[®] (Fig. 5.2) and HERMES[™], which are more advanced robotic systems; both based on voice-activated technology. The purpose of this chapter is to provide practical information for the pediatric surgeon regarding the use of AESOP[®] during commonly performed operations. The authors have used the AESOP[®] robot in over 100 minimally invasive surgeries in infants and children with weights ranging from 2 kg to over 100 kg.

General Overview

As mentioned previously, Computer Motion has developed the AESOP[®] device, which is a surgical robot capable of maneuvering and positioning an endoscope in minimally invasive surgery procedures. AESOP[®] approximates the form and function of a human arm and affords precise and consistent scope movements, which are necessary in pediatric minimally invasive surgery. AESOP[®] incorporates Computer Motion's speech recognition technology, which allows the surgeon to directly control the robot using simple verbal commands. AESOP[®] is the world's first FDA-cleared surgical robot and was introduced in October of 1994. Since then AESOP[®] has been used in thousands of minimally invasive procedures throughout the world.



Figure 5.1. AESOP® robot and mobile cart.

The AESOP® robot has been used in multiple surgical specialties, including minimally invasive cardiac surgery, gynecologic surgery, orthopedic surgery, adult and pediatric general and thoracic surgery, as well as others. Potential advantages of AESOP® include placing more control with the operative surgeon, provision of consistent, steady images, and decreased surgical operative time, possibly reducing operative costs by eliminating human assistance.

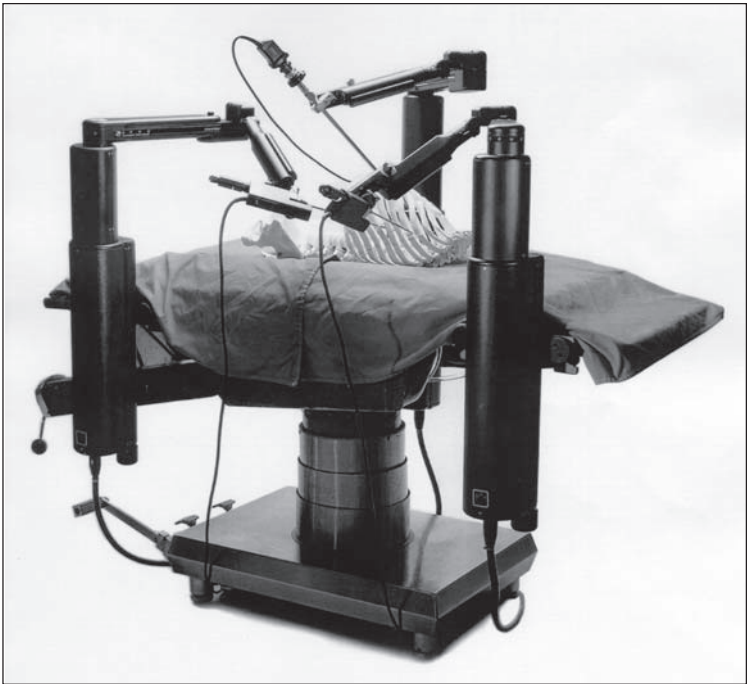


Figure 5.2. ZEUS[®] robotic arms simulation.

As mentioned above, an extension of AESOP[®] is the HERMES[™] operating room control center, which is a system capable of networking medical equipment in the operating room. HERMES[™] allows multiple compatible devices in the operating room to be networked through a centralized computer-controlling unit. HERMES[™] provides the surgical team with information regarding the operating status of each device, which is displayed on the video monitor, as well as audible voice feedback. This system allows surgeons to directly control these devices with simple verbal commands.

The ZEUS[®] robotic surgical system utilizes the robotics-forced feedback and speech recognition technologies to improve surgical dexterity and precision during complex minimally invasive surgical procedures. It is felt that ZEUS[®] will enable a new class of minimally invasive microsurgery procedures that are presently not possible using conventional techniques. ZEUS[®] is comprised of three interactive robotic arms that are placed at the operating table, a dedicated computer controller, and an ergonomically enhanced surgeon console. One robotic arm positions the endoscope while the other two manipulate surgical instruments under verbal control of the surgeon. While seated at the console, the surgeon views the operative site with a high-resolution monitor and operates handles that resemble conventional surgical instruments. With voice commands the surgeon controls the movements

of the endoscope and changes the view of the video monitor. The surgeon's hand movements are scaled and hand tremors filtered out by the computer and translated via the robotic arms into precise micromovements at the operative site. For example, the surgeon might move the surgical instrument handle at the console one inch, while the corresponding robotic instrument tip at the operative site moves only one tenth of an inch. In this operating environment, the surgeon is comfortable, ergonomically positioned and able to perform complex minimally invasive microsurgical procedures with greater precision. Although it is felt that the primary application of the ZEUS[®] technology will be with endoscopic coronary artery bypass grafting, this technology may well be applied to complicated minimally invasive surgical procedures in infants and children.

Technical Details

The AESOP[®] robotic arm resembles a human arm, with a post that attaches to the operating room table in a fashion similar to the Bookwalter retractor post. The arm consists of a proximal portion (closest to base), a flexible joint, and a distal portion with a coupler to secure the endoscope (similar to the human arm). The exact placement of the robotic arm depends upon the operation being performed, as well as the size of the patient. While the AESOP[®] robotic arm can be used for any minimally invasive operative procedure, we feel that its primary role will be in complicated, advanced minimally invasive operations in which there is limited movement of the laparoscope. Operations which meet these objectives include laparoscopic fundoplication with gastrostomy tube placement, laparoscopic colon pullthrough for Hirschsprung's disease, laparoscopic pyloromyotomy, laparoscopic cholecystectomy and appendectomy, laparoscopic splenectomy, laparoscopic adrenalectomy and thoracoscopic excision of mediastinal cysts, foregut duplications or tumors. The AESOP[®] robot is also helpful with thoracoscopic decortication of empyemas.

The use of the robot is fairly intuitive and requires minimal training of the surgical team. The robot does require the surgeon to create a voice card, which involves recording the surgeon's voice, giving approximately 20 simple commands over a range of volumes and speed of speech so that the voice-activated technology will work to the surgeon's advantage. Following creation of the voice card the surgical nurse must perform a few very simple procedures in order to attach a collar to the telescope, which will then couple with the AESOP[®] arm. After placing the robot on the operating table, we routinely set the lower limit ourselves prior to any covering of the patient in order to ensure safety during the operation. After the surgeon has verified correct positioning of the robotic base on the operating table, the correct arm position, the correct tilt of the robotic base, and set the lower limit, the patient can then be prepared for the operation in the usual manner.

Specific Procedures

Laparoscopic Nissen Fundoplication

The advantages of using AESOP[®] are most noticeable while performing fundoplication in very small infants. The authors routinely perform fundoplications via laparoscopic techniques in infants and children, down to the weight of 2.5 to 3 kg body weight. To proceed with this operation, the team must first place the

AESOP®'s robotic arm on the patient's right side on the operating table. The level of placement of the robotic arm should be such that the proximal arm can be extended over the table, perpendicular to the longitudinal axis of the table, and the distal arm of the robot should be placed at a 90° angle, which becomes parallel to the patient's body. No tilt is placed on the robot, and the elbow is placed in the -1 or -2 position (distal arm angled down approximately 30-45°). By placing the robot in this position there is no interference with subsequent instrument placement. In our experience, the optimal position of the cannulae for fundoplication includes a 5 mm cannula at the umbilicus and a 5 mm cannula in the left upper quadrant at the site of the G-tube. This position should be measured prior to insufflation of the abdomen and should be marked halfway between the umbilicus and the left costal margin. The 5 mm size is required for a harmonic scalpel device. Three additional cannulae are placed (all 3 mm). A 3 mm cannula is placed in the right upper quadrant, in the right lateral position, and the left lateral position. Through the right lateral 3 mm cannula, a liver retractor is inserted. This is then affixed to the table, using a Thompson retractor. The far left lateral 3 mm cannula is used for the assistant and the right upper quadrant 3 mm cannula is used for the left hand of the surgeon.

After placement of all cannulae, the endoscope is attached to the AESOP® device and, by working with the left and the right hands, the operation is conducted in the usual fashion. One important feature of the AESOP® robot is the ability to set three different positions that can be recalled at any time during the operation. We commonly set the first position with the telescope just inside the umbilical cannula to provide a panoramic view of the abdomen. Position number two is frequently a close-up view of the left paraesophageal region, which is used during dissection of the left crura, as well as division of the phrenoesophageal ligament. Position number three is of the right paraesophageal area, which is used during suture of the crura or the cruroplasty, as well as suturing of the fundoplication itself.

After fundoplication the telescope is then retracted so that it is just inside the cannula at the umbilicus and is focused on the left upper abdominal wall for G-tube placement.

In performing over 75 such operations, we feel that the AESOP® robot provides very safe and consistent imaging, which is required during this complicated operation. This also places more of the operation into the surgeon's hands and eliminates an additional assistant. With the liver retractor attached to a Thompson retractor, which affixes to the bedside, this also eliminates an assistant. This operation, even on the smallest of infants, can be done with the surgeon and one assistant, who operates the left upper quadrant instrument and cannula, which is needed for traction and countertraction while doing the dissection. The average operative time during these operative procedures is 1.5 hours.

Laparoscopic Pyloromyotomy

The positioning for laparoscopic pyloromyotomy is exactly the same as for the fundoplication described above. The placement of cannulae during this operation is as follows: A 2 mm or 3 mm cannula is placed at the umbilicus through which the pneumoperitoneum is achieved, and a 2 mm or 3 mm telescope is introduced. Two stab incisions are made with an 11 scalpel in the right upper quadrant and left upper quadrant. Through these stab incisions, 3 mm instruments are advanced directly

into the abdominal cavity. After placement of the instruments the AESOP®'s robotic arm is attached to the laparoscope and this provides a panoramic view of the area. During laparoscopic pyloromyotomy there is very minimal camera movement; however, very precise movements are needed, given the small size of such infants and optimal viewing of the pyloric area is essential to performing a safe pyloromyotomy. In the authors' experience, this can best be achieved using the AESOP® robot and the pyloromyotomy is made using a disposable retractable arthroscopic blade. Following creation of the incision through the pylorus, the blade is retracted and then exchanged for a 3 mm laparoscopic pyloric spreader. After spreading of the myotomy the anesthesiologist injects air into the stomach via an indwelling orogastric tube, which ensures that there has been no unidentified perforation in the duodenal mucosa. After visualizing and confirming an adequate pyloromyotomy, the instruments are then removed as well as the telescope, and the small umbilical cannula site is closed with absorbable suture. The orogastric tube is removed while the patient is still in the operating room.

Laparoscopic Cholecystectomy

While laparoscopic cholecystectomy is somewhat rare in the pediatric population, the AESOP® robot can provide optimal positioning of the laparoscope during this operation as well. In our experience, the optimal positioning for the base of the robot is on the right side of the patient, at the level of the iliac crest. The upper portion of the arm is in position directly across the table, and the distal part of the arm is at a right angle, thus becoming parallel to the patient. The elbow is usually kept at the zero position, with no angle applied. In very obese or large patients, the robot at times will need to be tilted somewhat toward the patient. One technical detail is that when tilt is needed, the tilt should always be toward the operative incision. After placement of the 5 mm or 10 mm cannula at the umbilicus, a pneumoperitoneum is achieved and the laparoscope is introduced. Additional cannulae consist of a 5-mm cannula in the right lateral position, a 5 mm cannula in the right mid-axillary line below the costal margin, and a 5 mm or 10 mm cannula in the mid-epigastrium.

Laparoscopic Splenectomy

In children, the most common diagnosis leading to this operation is hereditary spherocytosis and other hematologic abnormalities. The authors position the patient in the supine position, with the left hip and shoulder elevated 45° on a beanbag device. After positioning in this manner, rotate the table such that the patient is in either the supine position or the right lateral decubitus position. The patients' left arm can either be tucked alongside the body wall or placed out on an arm board to the left. The optimal positioning of AESOP® in this operation is, again, at the patient's right mid-thigh. However, during splenectomy it is best if the upper part of the robot arm parallels the patient's body on the operative table, and the distal part of the arm angles up (elbow at +1 or +2) at approximately 45°, toward the umbilicus. The proximal robotic arm is kept low, approximately at table level, which decreases interference with the remainder of the operation. This allows additional cannulae to be placed in the midepigastric area (usually a 3 mm cannula), as well as the right lower quadrant (5 mm cannula). The 5 mm cannula is required for a laparoscopic

5 harmonic scalpel device, which is useful during this operation. The umbilical port, which is where the camera is placed, is typically a 5 mm or 10 mm cannula. The spleen is then dissected from surrounding structures and all splenic attachments are divided using the harmonic scalpel. The authors typically like to start at the lower pole of the spleen, dividing the splenicocolic and splenorenal ligaments with the harmonic scalpel. The dissection is then carried lateral and posterior to the spleen, again going from the lower pole to the upper pole. Frequently this part of the operation is aided by the use of a 30° telescope. Following this dissection, attention is then turned to the upper pole and these attachments are then divided, which only leaves the hilar vessels. At this point, the telescope (usually 5 mm) is changed to the left lower quadrant cannula and an endoscopic stapling device is used, via the umbilical cannula, to staple across the splenic vein and artery. An endoscopic tissue retrieval bag is introduced through the umbilical port. This requires a 15 mm cannula, which is provided with the endoscopic tissue retrieval bag. After successfully placing the spleen in the endoscopic specimen bag, the spleen is then pulled up to the anterior abdominal wall through the umbilical port. The camera is then moved to another location to allow visualization of removal of the spleen. The spleen is then removed using blunt techniques through the bag.

Laparoscopic Appendectomy

For appendectomy, the position will greatly depend on the patient's size. However, a general rule is to place the AESOP®'s base on the patient's left hip and place the upper part of the arm parallel to the operative table along the patient's left side. The distal part of the arm will then angle toward the patient in the +1 or +2 position. Additional cannulae are placed according to the surgeon's preference. The authors use a 12 mm trochar at the umbilicus, 5 mm in the left lower quadrant and a 3 mm or 5 mm cannula suprapubically. After creation of a pneumoperitoneum through the umbilical port, the additional cannulae are placed. The camera is moved to the left lower quadrant 5-mm cannula site and the umbilical port and the suprapubic port become the left and the right working ports for the surgeon. With AESOP® allowing manipulation of the camera, this operation can be performed just with the operative surgeon, requiring no assistance. The appendix is identified, a window is made in the mesoappendix, the mesoappendix is stapled with vascular staples and the appendix is then stapled with standard tissue staple cartridge. The appendix is removed through the umbilical port either with or without a specimen bag.

Laparoscopic Colon Pullthrough for Hirschsprung's Disease

Several neonatal laparoscopic pullthroughs have been done by the authors using AESOP® to control the camera. Typically, the infant is placed transversely on the operating table at the end of the table away from anesthesia. The patient is prepped from nipples to feet circumferentially and an extremity drape is used to prep the entire baby within the field, from the nipples down. Placement transversely on the operating table allows the surgeon optimal positioning during the laparoscopic portion of the procedure, as well as during the perineal portion of the pullthrough. The initial cannula placement for a laparoscopic pullthrough is a right upper quadrant 3 mm or 5 mm cannula, using an open technique. After placement of this cannula, a pneumoperitoneum is achieved and the camera is introduced. AESOP® is placed on

the left side of the operating table with the upper part of the arm parallel to the operating table and the distal part of the arm angled toward the baby. This allows placement of additional cannulae in the left lower quadrant, as well as the right lateral position, which allows optimal exposure and access to the pelvis. After placement of the cannulae and positioning of the AESOP® device, the colon is then mobilized to the transition zone, where a biopsy is taken to confirm the presence of ganglion cells. The pelvic dissection is performed and attention is turned to the perineal portion of the pullthrough procedure.

Thoroscopic Excision of Mediastinal Mass or Tumor

The specific location of AESOP® will obviously depend upon the side of the approach for these tumors, although more commonly a right-sided thoroscopic approach will be used for biopsy and excision of these lesions. The general principle of using AESOP® during thoroscopic surgeries involves placing the base of AESOP® on the same side as the surgeon. The base of the robot should be typically at the patient's hip and kept low on the operating table. The upper part of the robotic arm is parallel to the operating table and the patient, and the distal part of the arm is angled up in the +1 or +2 position, and toward the patient. This allows additional cannulae to be placed as needed and allows the surgeon to work above the robotic arm so that minimal interference will be experienced during these operations. It is also essential during these operations that one-lung ventilation can be implemented, therefore providing adequate visualization of the structures of interest. Techniques on how to provide this can be found in other chapters of this text.

Thoroscopic Decortication of Empyema

The use of AESOP® during this operation provides stable and consistent views of the affected hemithorax. The use of AESOP® is very beneficial during this operation in that there is minimal endoscope manipulation involved during this operation, although these operations can be lengthy, depending on the degree of disease found in the hemithorax. The position of the patient is the lateral decubitus position, as for an open thoracotomy. A 5 mm cannula is placed in the mid-axillary line low in the hemithorax, which can also be used for the chest tube at the conclusion of the case. The telescope is introduced through this cannula and then attached to the robotic arm. Again, we have found this best placed on the same side as the surgeon, with the upper arm low and parallel to the operating table and the patient, and the distal part of the arm at the +2 position, angling toward the patient. With panoramic views of the thorax, additional cannulae can be placed as needed for the suction-irrigating device, as well as a grasper. By using this basic setup, most empyemas can be successfully decorticated thoroscopically.

Pitfalls with Use of AESOP®

As with most minimally invasive surgical techniques, there is a learning curve to using AESOP® effectively. Many surgeons are skeptical of added time in setting up for these procedures, as well as extensive procedures which need to be learned by the operating room personnel. We have found that the time savings during operation are such that this is effective and that there is actually very little that operating room personnel must learn in order to use this system effectively. However, with experience in using AESOP® the surgeon does become more comfortable with use of the

robot and learns the specific position that he or she feels is most beneficial for various size patients.

Another potential difficulty is in using AESOP®'s voice activated recognition technology. The creation of the voice card by the surgeon is often done in the quiet, no-stress situation of the surgeon's office. However, during these complicated operations the volume as well as the speed of the surgeon's speech often changes. Thus, the robot may have difficulty recognizing the surgeon, which adds to the surgeon's frustration. Thus, it should be remembered that the robot works most effectively

Mini-Laparoscopy in Infants and Children

Thom E Lobe

Introduction

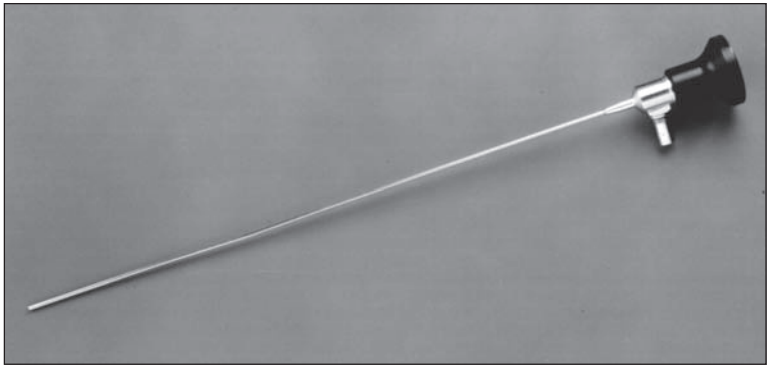
In the beginning, most laparoscopists used 10 mm laparoscopes for their minimally invasive surgery. There were a few of us, particularly in Pediatric Surgery, who already had smaller scopes (those they usually used for bronchoscopy or cystoscopy) that they used on a regular basis for their laparoscopic and thoracoscopic procedures. At that time, however, the quality of the optics in the small, rigid Hopkins rod lens scopes was not very good for laparoscopy. High resolution and good visibility in the relatively large body cavities was not adequate either for diagnostic work or manipulative surgery. The prevailing thought at the time (mostly amongst adult laparoscopists), was that a trocar site sufficiently large to accept a 10 mm scope (usually on the order of 12 mm), was acceptable because high quality images were so important.

Most of the pediatric surgeons who did a relatively large volume of endoscopic surgery used the instruments that were readily available, a combination of 10 mm and some 5 mm devices. We recognized, however, that even the 5 mm instruments were too large for most of the procedures we wanted to do in infants and children. Accordingly, we begged the instrument companies to design smaller instruments suitable for our patient population. The issue was one of marketability. Few manufacturers were willing to work with us to develop suitably small instruments for pediatric use.

In fairness to our partners in industry, there were several technical hurdles to overcome. Regarding the ultra small telescope, one must have superior optics in a durable instrument while at the same time be able to deliver sufficient light to illuminate a relatively cavernous space. Part of the problem here was the video technology that had to provide a high resolution, highly light sensitive camera to use in conjunction with these tiny scopes. As time has passed, we saw the development of improved video cameras that were suitable for use with the newer smaller scopes.

Improvement in fiber optic technology has allowed the development of suitably small telescopes. These scopes, while they do not provide the crisp, clear image of a rod lens telescope, still provide a relatively high quality image depending on the number of fibers used. The scopes now have about 80,000 fibers or more in a 1.7 mm telescope (Fig. 6.1). One of the advantages of the fiber optic scope that gives it more durability is the fact that the fibers can bend slightly without breaking, while a similarly small rod lens scope cannot.

The instruments themselves proved to be another challenge. How small is too small? There is a point at which the instruments become so small that they are too



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Figure 6.1. Mini-Site® 1.7 mm scope. Courtesy of AutoSuture, a division of Tyco.

flimsy to be of any use. This is compounded when one wants an instrument that opens sufficiently wide to grasp, cut, perform a biopsy or manipulate a needle for suturing. Several iterations of instruments have been proposed and tried. These include fine instruments, stabilized by passing them through a 14 gauge needle introducer, that proved too flimsy to be of much use, and have evolved into more usable instruments of about 1.7 mm in diameter. This diameter, something just less than 2 mm, seems to be about the smallest size of any utility today and probably will remain so until stronger materials and designs become available (Fig. 6.2).

It's somewhat amusing to us that, given the availability of better video technology and smaller instruments, the same adult surgeons who touted the use of the 10 mm scope and instruments now speak of the advantages of using these smaller instruments. They dubbed the procedures using these new instruments mini-laparoscopy or "needlescopy". In adults, many of these procedures can be carried out under a local anesthetic, with or without conscious sedation.

As far as pediatric surgery is concerned, there are many procedures that can be carried out using needle-like instruments and scopes. A list is provided in Table 6.1. Simple procedures such as looking to establish a diagnosis or performing a biopsy are easy to perform. Simple procedures that don't require suturing can be performed satisfactorily using the small instruments, so long as suturing isn't required. It's not that suturing is impossible. On the contrary, one can pass a suture through the abdominal wall and use a 1.7 mm grasper to accurately and securely place a suture if one is accomplished at intracorporeal knot tying. But it helps to be an expert at intracorporeal suturing if one attempts to do this using the small instruments.

Among the disadvantages of using the small instruments is an issue unique to the small patients on whom we work. The tissue in infants is delicate, soft and easily cut when manipulated or grasped with instruments that are particularly small and "knife-like." For example, if we grasp the small bowel of a newborn, the potential exists for "cutting" through the bowel wall and ending up with a hole that needs repair. The more edematous the tissue, the more likely this is to occur.

Another disadvantage is that the currently available instruments are not adequately insulated for use with electrocautery. Thus, if hemorrhage occurs you either have to

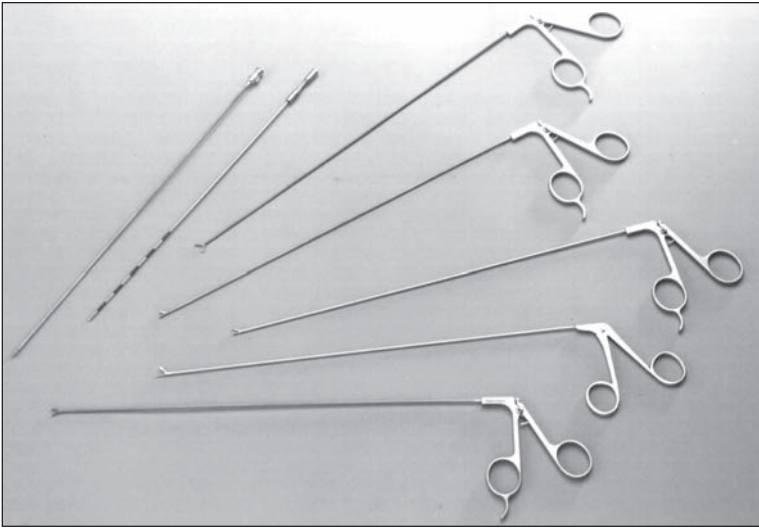


Figure 6.2. Mini-Site® Instrument. Courtesy of AutoSuture, a division of Tyco.

use sutures or some other form of energy, such as fiber optic laser, for control of the blood loss.

Some surgeons may find it difficult to see well enough with the small scope, depending on their video system. To use the small scopes effectively requires a state of the art video set-up. The optic coupler becomes important so that the image fills the screen. One solution is to use a camera with a zoom feature. That way, the image size can be adjusted depending on the needs of the surgeon. Unfortunately, the resolution and visibility decreases as the image is enlarged with the zoom. The light delivery system is limited. The 1.7 mm scope comes with its own light cable which is calibrated so that the light (heat) delivered won't overwhelm the capacity of the delicate scope. In other words, if you try to deliver more light, you may melt or burn the fibers in the scope.

Advantages of using the needle-like instruments are obvious. First and foremost, there is the cosmetic advantage. The holes made by the 2 mm trocars are tiny and in most cases, don't even need suturing but can be closed simply with a paper adhesive strip, a surgical adhesive or even a simple bandage. Thus patients and/or their families who are concerned about surgical scars are quite pleased with the postoperative appearance after "needleoscopy".

The other obvious advantage is postoperative discomfort. It appears to be true and stands to reason that the smaller the hole, the less the discomfort. Patients who undergo procedures with the small instruments rarely complain of postoperative pain any greater than they would complain of discomfort from a needle stick anywhere else.

To perform "needleoscopy" one uses techniques that, for the most part, are already familiar. The cannulae are placed using a Veress needle introducer (Fig. 6.3).

Table 6.1. Mini-laparoscopic procedures in infants and children

Diagnosis	Abdominal Pain Childhood Malignancies Inguinal Hernia Undescended Testes Intersex Trauma Inflammatory Conditions Intracavitary Infection Intracavitary Cysts
Biopsy	Infection Childhood Malignancy Inflammatory Conditions Endometriosis
Procedures	Gastrostomy Undescended Testes Pyloromyotomy Fenestration of Cysts
Potential Procedures	Appendectomy Cholecystectomy Ovarian Cystectomy

For laparoscopy care is taken to ensure that the stomach and bladder are first emptied. Oro- or nasogastric suction should be sufficient to empty the stomach. Either bladder catheterization (for older patients or patients undergoing pelvic endoscopy) or the Credé maneuver is used to empty the bladder.

With the patient in Trendelenburg position, a tiny stab wound is made in the umbilicus with a #11 blade (just large enough to accommodate the 2 mm cannula). The Veress needle then is introduced into the peritoneal cavity in the usual fashion. Its intraperitoneal position can be verified by a falling drop test, using the “blind man’s cane” or “windshield wiper” maneuver, or simply by connecting the insufflator tubing and turning on the flow of CO₂. The flow should be at least 1 L/min. It may be helpful to lift the abdominal wall, especially in the infant or small child, to make certain that the tip of the Veress needle isn’t buried in the omentum or bowel.

When the flow slows to below 1 L/min, the Veress needle is removed and the 2mm cannula is secured over the Veress needle introducer. The cannula and Veress needle are then reinserted through the same stab wound (allowing the gas to escape through the open stopcock to verify placement), the Veress needle introducer is removed and the telescope is introduced. It is helpful to warm the telescope before hand to minimize fogging of the lens.

Secondary trocars are inserted under direct vision as needed for the procedure. Usually it is safe to introduce the combined cannula/Veress needle introducer as a unit. There are some procedures for which an instrument is inserted directly through a stab wound in the abdominal wall to obviate the need for a larger cannula. Pyloromyotomy is a good example of this (Fig. 6.4).

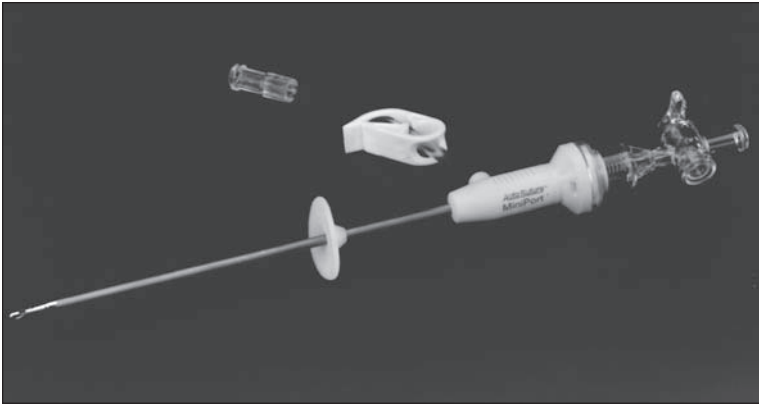


Figure 6.3. Mini-Port® with Veress needle. Courtesy of AutoSuture, a division of Tyco.

Diagnostic Laparoscopy

For diagnostic work, the telescope is inserted as described above. Depending on the specific question, inspection is systematic. For a general inspection, we start in one location of interest and in a systematic fashion, move from place to place. For example, we already have the patient in the Trendelenburg position, so it is logical to inspect the pelvis first. Then we rotate the patient to one side and inspect that lateral gutter, move the patient in reversed Trendelenburg position and inspect the upper abdomen, rotate the patient to the other side and inspect the opposite lateral gutter and end up back in the pelvis. Some of this can be done simply with the telescope in place. There may be areas of special interest, however, that require closer inspection or the manipulation of viscera to see better. To accomplish this, we introduce one or more secondary cannulae and insert probes, graspers or other instruments to move structures in order to see better. As with any endoscopy, the closer we move the telescope toward the subject of interest, the better we can see. Doing this not only brings us closer to the subject, but the light appears brighter because the tip of the telescope from which the light emanates is closer and thus throws more light on the subject. The quality of the images is sufficiently good to see lesions only a fraction of a millimeter in size, although it is not quite as crisp an image as one might expect using a rod lens telescope.

This sort of procedure is good in most of the instances for which we simply need to look, examples of which are listed in Figure 6.1.

Biopsy

When one needs to biopsy a suspicious lesion, a second port is required to be placed so that the biopsy forceps will be within easy reach. One must keep in mind that the size of the biopsy obtained can be no larger than the diameter of the biopsy forceps.

Deeper biopsies can be carried out by using a Tru-Cut needle biopsy directly through a stab wound or trocar site, except in case of primary malignancy where the tumor stage might change by the spillage of tumor or implantation in the biopsy track might occur.

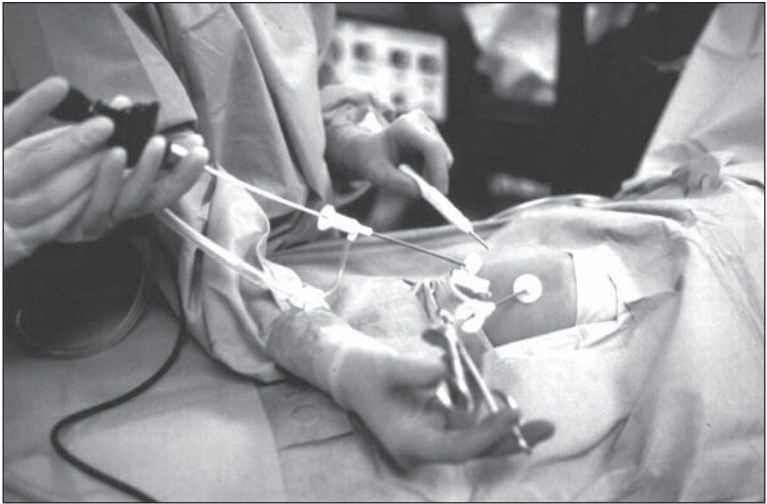


Figure 6.4. Set-up for needleoscopic approach to laparoscopic pyloromyotomy.

We have diagnosed fungal infections, Cat Scratch disease and other similar lesions on the surface of the liver in cancer patients suspected of metastatic disease using this technique.

Procedures

Gastrostomy

Gastrostomy is often required in children who cannot eat on their own for a variety of reasons. While some prefer a percutaneous endoscopic gastrostomy (PEG), we believe that a laparoscopic gastrostomy offers several advantages. First, the risk of the injury to the colon or small bowel or aberrant placement of the PEG tube into either of these structures can be eliminated. Perhaps more importantly, we find that the initial or primary placement of a gastrostomy button is both feasible and desirable.

Before the abdomen is insufflated, we mark where we want to place the gastrostomy button on the patient's abdomen. Then we place the umbilical cannula for the telescope and inspect the abdomen to make certain that the stomach is suitably located.

A 4-5 mm incision is made in the skin at the proposed gastrostomy site and a second 2 mm cannula is introduced through this incision. Using a 1.7 mm locking grasper, a point on the greater curvature of the stomach, midway between the pylorus and the gastroesophageal junction (or more proximal), is retracted toward the anterior abdominal wall cannula site.

For patients whose abdominal wall is 1.0 cm or less thick, we use two 2-0 suture on a CT-1 needle. The first is inserted just medial and slightly cephalad to the proposed gastrostomy site to pass through the abdominal wall, catch a generous bite of the gastric wall medial to the grasper's jaws and back out through the abdominal

wall. The ends of this suture are grasped in a hemostat to use later to secure the button. A second suture is placed in a similar fashion just lateral to the proposed site.

A Cook vascular dilator set (Cook Inc, Bloomington, IN) is introduced using the Seldinger technique to dilate the track, and the selected button is passed over the guidewire using the 8 F vascular dilator as a stent/guide. Once the balloon tip of the button is well into the stomach, the balloon is filled with 5 cc of normal saline and the ends of the two sutures are tied over the ends of the button to hold it in place. Before withdrawing the umbilical cannula, we test the button by filling the stomach with saline to make certain that there are no leaks.

This is an extremely effective way to place a primary button in a precise location on the gastric wall using relatively atraumatic techniques.

We leave the feeding tubing connected to the button for about 5-7 days before removing it and instructing the parents in its use. We cut the sutures at about 48 hours and discontinue antibiotics (usually a cephalosporin) at that time.

Pyloromyotomy

Laparoscopic pyloromyotomy is performed in many centers on a routine basis. We prefer to use the needle scope for this operation as it requires no sutures and is quicker to perform.

Patients with idiopathic hypertrophic pyloric stenosis are prepared for surgery by rehydrating them and correcting their metabolic derangement. The umbilical trocar is placed as described above, the abdomen is inspected, and the diagnosis is confirmed.

A second cannula is inserted in the left upper abdomen at about the anterior axillary line, between the level of the umbilicus and rib margin. This is for the stomach grasper.

A mirror image stab wound is made on the right side using a #11 scalpel blade. A disposable, retractable arthroscopy blade (Linovatec Corporation, Largo, FL) and pyloric spreader (Jarit, Hawthorn, NY) are used through this stab wound.

The gastric antrum is grasped, just proximal to the pyloric tumor, from the patient's left and held for the duration of the procedure. The arthroscopy blade is extended and used to longitudinally score the pylorus from the antrum to just proximal to the pyloric vein. This incision is deepened with the blade or its sheath. The blade is replaced with the pyloric spreader which is used to spread the muscle until the mucosa bulges and the two halves of the muscle move independently. We finally check the pyloromyotomy for leaks by instilling air via an orogastric tube and watching for bubbles at the myotomy.

The instruments all are removed and closed as described above without sutures. Patients are fed within 4 h and this is advanced as tolerated. Usually, they are discharged the next day.

Undescended Testes

Laparoscopic exploration for intraabdominal testes now is standard procedure in most pediatric centers. When a high intraabdominal testis is found, there are several options. We perform a two-stage orchiopexy. To do this requires an umbilical port and one or two secondary ports.

The testicular vessels first are divided using a laser fiber. At a second procedure 3-6 months later, two additional ports are placed, one suprapubically in the midline or on the contralateral side, midway between the umbilicus and the contralateral superior spine of the iliac crest and one midway between the umbilicus and the ipsilateral superior spine of the iliac crest. These ports are used for a grasper and scissors to mobilize the testis with a pedicle of peritoneum, thus freeing it sufficiently so that it can reach into the scrotum.

A transverse incision is then made in a dependent portion of the scrotum and a dartos pouch is created. A 5 mm trocar then is inserted through the scrotal incision and advanced along the inguinal canal into the peritoneal cavity just medial to the inferior epigastric vessels. Using a 5 mm grasper passed through this trocar, the testis is grasped and drawn into the 5 mm cannula and into and sutured into the dartos pouch.

Fenestration of Ovarian Cyst

Large, simple ovarian cysts, occurring in infants, that do not resolve spontaneously can be treated laparoscopically by fenestration using the small instruments. The umbilical cannula is placed first for the telescope, and the cyst is inspected to make certain of the diagnosis. The cyst then can be aspirated by inserting a needle percutaneously, and a section of the wall of the cyst can be removed using the 1.7 mm mini-shears. The resulting hemorrhage either is minimal, or an energy device such as a laser can be used to stop the hemorrhage. Any specimen of the wall can be extracted through one of the trocar sites.

Potential Procedures

The 1.7 mm instruments, while small, can be used to carry out relatively demanding tasks if one simply has the ingenuity and perseverance. If one is so inclined as to attempt the removal of an appendix or gallbladder, the tiny instruments can be used to manipulate and tease tissues apart, or to dissect and divide structures. Parts of these procedures require larger instruments, particularly if one wants to use clips, staplers or other larger devices. At the very least, the 1.7 mm telescope is more than adequate to perform an appendectomy, cholecystectomy or other similar procedure. The instruments must be used with care so that edematous or friable tissues are not severed inadvertently with a tiny-jawed grasper.

As technology continues to advance, we will see downsizing of many more instruments because of the advantages of less pain and better postoperative appearance of the wounds that one sees with the use of mini-laparoscopy.

Diagnostic Laparoscopy for Contralateral Patent Processus Vaginalis

George W. Holcomb, III

For the past 50 years, surgeons have wrestled with the question regarding the contralateral inguinal region in an infant or child with a known unilateral inguinal hernia. A number of publications have advocated bilateral hernia repair, unilateral hernia repair with observation of the contralateral region or laparoscopic evaluation of the contralateral region.¹⁻⁷ There is probably not a correct answer as to which approach is best, although laparoscopic inspection of the contralateral inguinal region affords the surgeon the opportunity to know in which child a contralateral patent processus vaginalis (CPPV) is present and in which child it is not. However, it is still not possible to determine whether or not the CPPV will become symptomatic in the future.

There are several approaches for laparoscopic inspection of the contralateral inguinal region. Initially, we performed the laparoscopy through a 3 mm umbilical incision.⁸ In 1994, however, the route of inspection was changed through the known hernia sac.^{9,10} Georgeson and colleagues have advocated creation of the pneumoperitoneum through the known inguinal hernia sac with in-line inspection through a 14 gauge angiocatheter placed near the contralateral inguinal region.¹¹ The technique of diagnostic laparoscopy through the known inguinal hernia sac is described below.

Technique

Following induction of general anesthesia, whether using endotracheal, LMA or Mask techniques, the patient's bladder is emptied using a Credè maneuver. This is more important in younger infants with a large bladder as visualization of the contralateral inguinal region through the known inguinal hernia sac can be more difficult with a distended bladder in young infants.

Using an inguinal crease incision, the external oblique fascia is incised and the hernia sac dissected from the adjacent spermatic cord. The sac is traced proximally to the level of the internal inguinal ring where it is opened. A 3 mm blunt-tipped cannula is then introduced into the abdominal cavity followed by insufflation through the side arm of the cannula to create an adequate pneumoperitoneum. (Figs. 7.1 and 7.2) Diagnostic laparoscopy is then performed using a 70°, 2.7 French telescope. (Figs. 7.3-7.5) The findings are noted, the telescope is withdrawn and the abdomen is deflated. High ligation of the known hernia sac is then accomplished followed by closure of the inguinal incision. Contralateral inguinal exploration is then performed if a CPPV is documented.

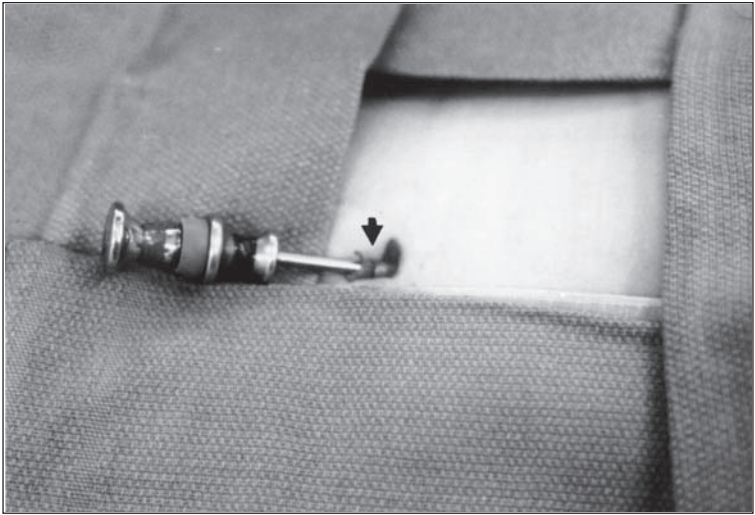


Figure 7.1. A 3 mm blunt tipped cannula is introduced through the ipsilateral hernia sac and the neck of the sac is secured around the cannula (arrow).

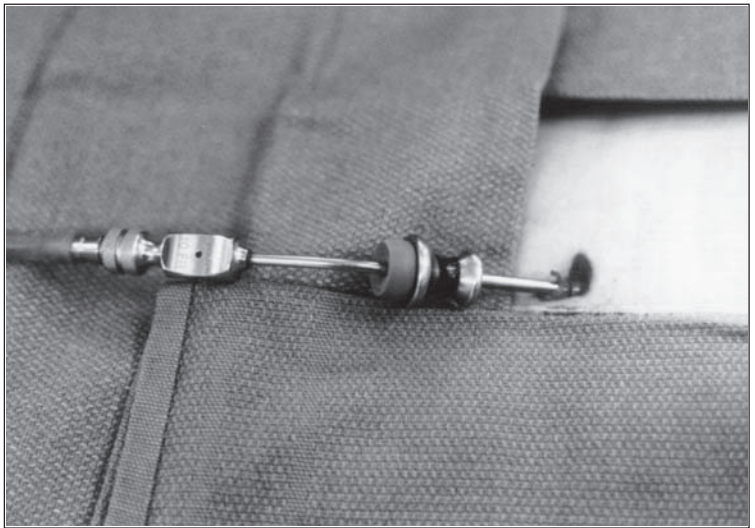
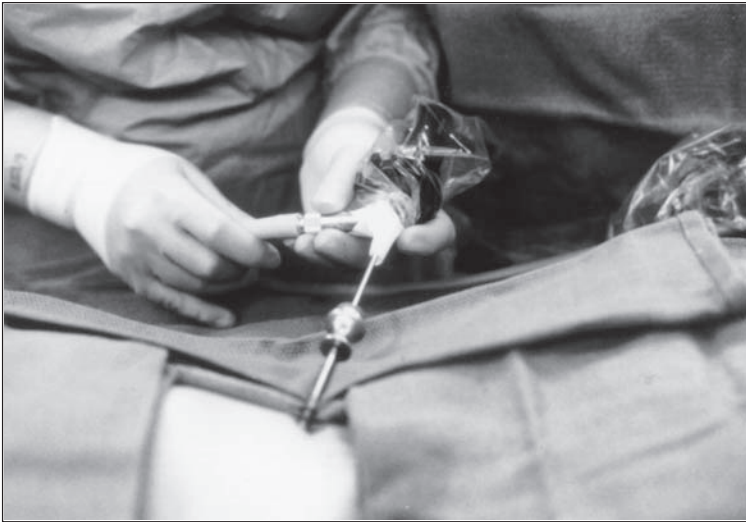


Figure 7.2. In this photograph, the reusable cannula does not have an insufflation port. Therefore, a reusable 10 suction cannula is connected to insufflation tubing and introduced through the port to create adequate pneumoperitoneum.



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Figure 7.3. A 70 degree, 2.7 telescope is introduced through the 3 mm cannula once an adequate pneumoperitoneum is established.

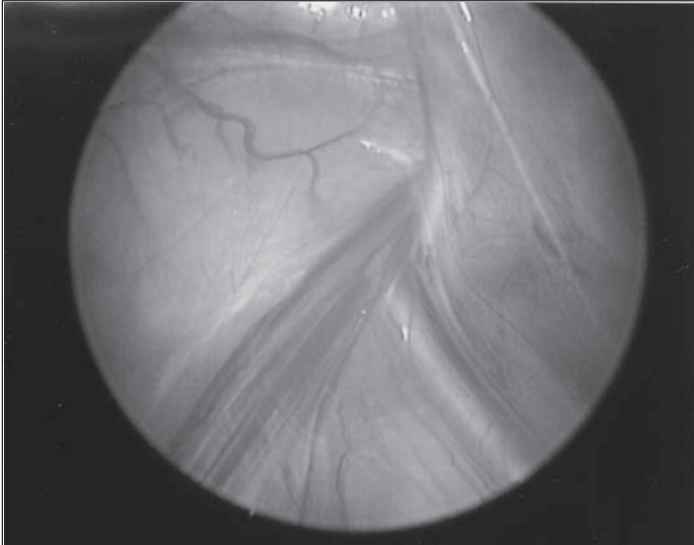


Figure 7.4. In this 6-month old boy, diagnostic laparoscopy is performed through the known right inguinal sac. There is no evidence of a hernia on the left side. The vas deferens and testicular vessels are clearly seen entering the closed internal ring.

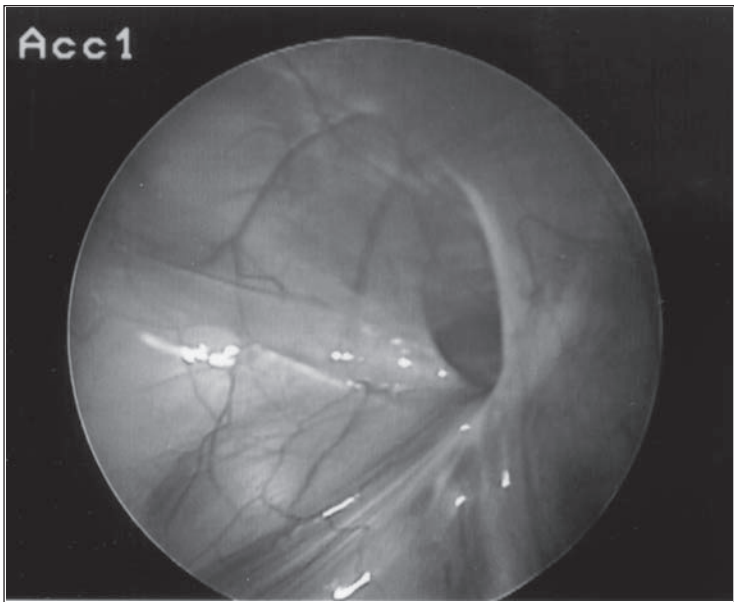


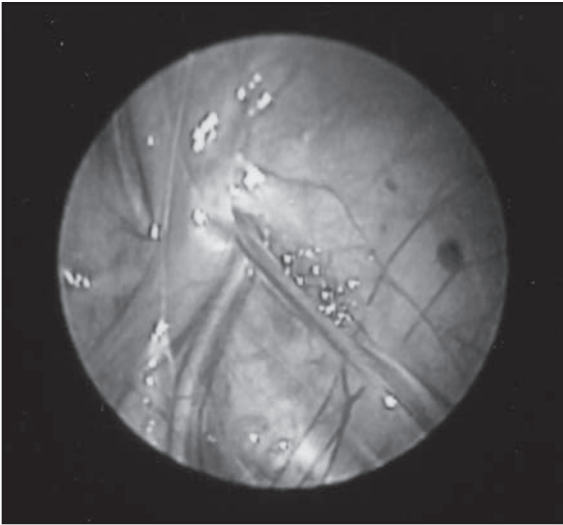
Figure 7.5. In this 4-year old boy, a contralateral patent processus vaginalis is not suspected on the left side. Diagnostic laparoscopy through the right inguinal hernia sac allows the surgeon to diagnose a contralateral patent processus vaginalis on the left side. Prior to 1994, diagnostic laparoscopy was performed through the umbilicus.

Comments

In 90-95% of the cases, it is evident whether or not the patient has a CPPV. By using the 70°-angled telescope, it is usually possible to visualize and insure that the depth of the CPPV is sufficient to warrant exploration of that side. On occasion, bubbles of CO₂ will be noted exiting the CPPV. The bubbles usually indicate a CPPV of sufficient length to warrant repair. (Fig. 7.6) On rare occasions, it is not possible to be sure of the depth of the CPPV. In this instance use of in-line visualization as described by Georgeson et al may be helpful. Another useful technique is to introduce a 12 gauge angiocatheter under direct visualization into the lower abdomen on the contralateral side through which a small silver probe is introduced to measure the depth of the CPPV or to retract the peritoneal veil to visualize better the depth of the CPPV (Figs. 7.7-7.10).¹²

Clinical Experience

Since May 1, 1992, over 1000 infants and children have undergone a diagnostic laparoscopy under a study protocol at Vanderbilt Children's Hospital, Nashville, Tn. and Children's Mercy Hospital, Kansas City, Mo. In the first 377 patients, diagnostic laparoscopy was performed using an umbilical cut-down technique. However, since that time, the remaining patients have undergone laparoscopy through



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Figure 7.6. Bubbles are seen exiting a small CPPV. The appearance of the bubbles usually indicates a CPPV of sufficient length to warrant contralateral exploration and CPPV ligation.

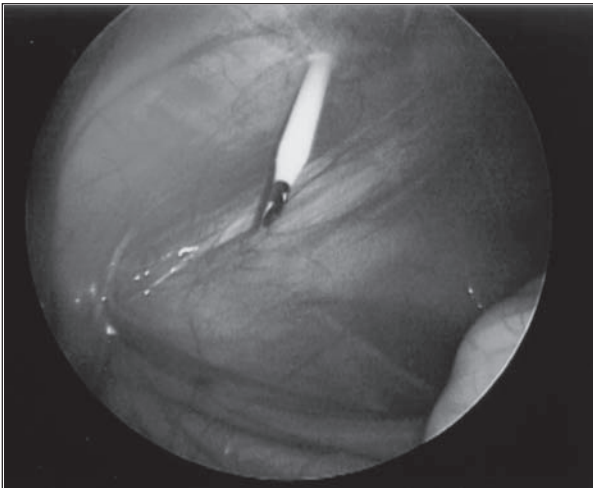


Figure 7.7. In this 8-month-old with a known left inguinal hernia, it is unclear whether the patient had a CPPV on the right side. On initial appearance, there is a veil of tissue overlying what appeared to be a patent processus. Due to the uncertainty, a 12 gauge angiocatheter is introduced under direct visualization into the right lower abdomen under direct vision.

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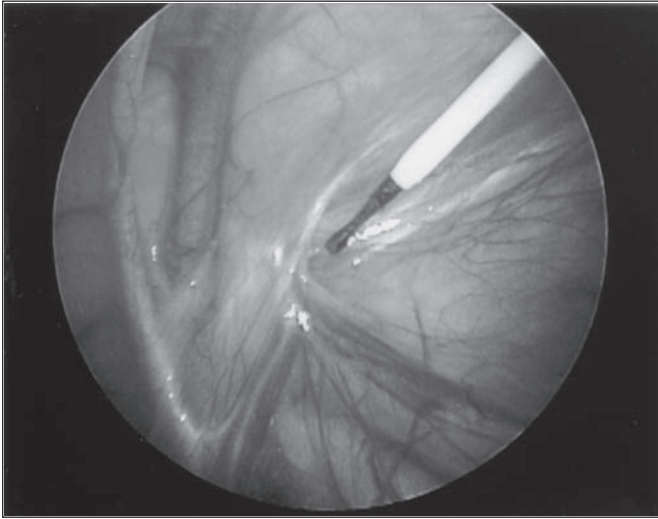


Figure 7.8. A small silver probe is introduced through the 12 gauge angiocatheter and positioned near the veil of peritoneum overlying the possible CPPV.

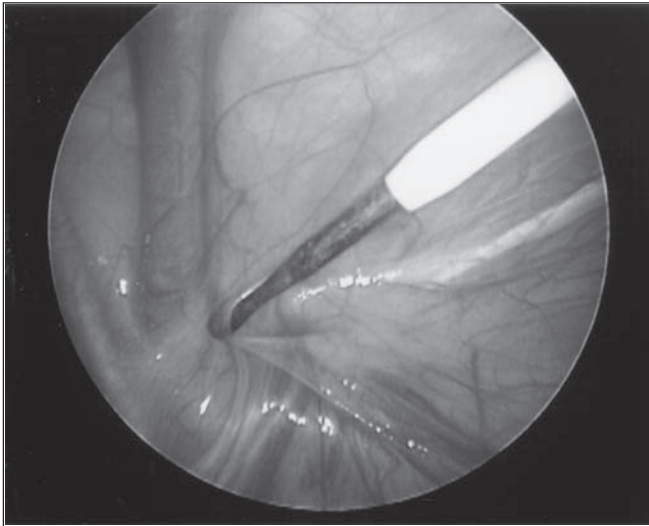


Figure 7.9. The veil of tissue is retracted exposing a small indentation of peritoneum but no evidence of a CPPV.

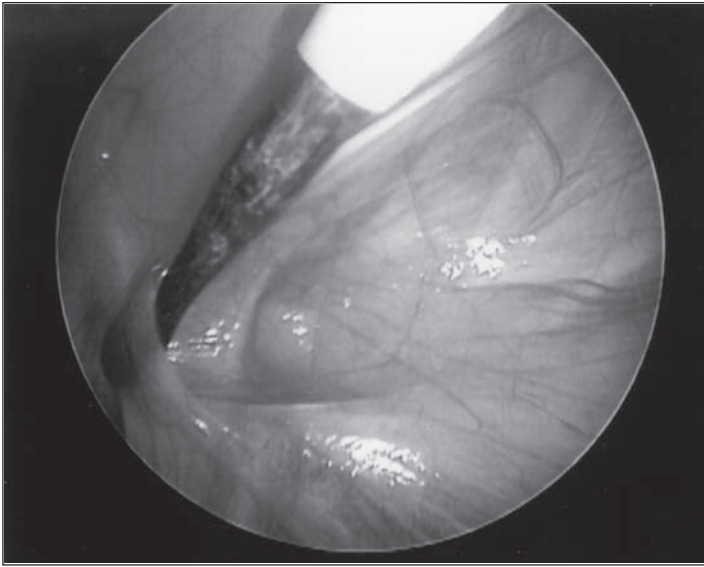


Figure 7.10. On closer inspection, the blind ending peritoneum is readily visualized and there is no evidence of a CPPV.

the known ipsilateral hernia sac. Neither age, gender, physical examination nor the Goldstein test have been predictive of whether or not a CPPV exists on the other side. Therefore, laparoscopy is the best method to evaluate the contralateral inguinal region and determine whether or not a CPPV is present. As contralateral exploration and ligation of a CPPV is a brief procedure with minimal morbidity, it is recommended that those patients with a CPPV undergo ligation at the time of the initial inguinal hernia repair.

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Laparoscopy for the Non-Palpable Testis

George W. Holcomb, III

One of the earliest descriptions of the use of laparoscopy in children was in the diagnosis and treatment of boys with non-palpable testes.¹⁻⁵ The laparoscopic one-stage or two-stage Fowler-Stephens orchiopexy for their abdominal testis has become the preferred approach for many surgeons for this condition.

In boys who present with a non-palpable testis on either one or both sides, three distinct scenarios apply. The testis may have undergone in utero torsion during its descent into the scrotum and atrophied. This torsion may have occurred in the retroperitoneum, inguinal canal or scrotum. Another explanation is that the testis is viable, although small, and resides in the inguinal canal where it cannot be palpated. In this situation, the testis often lies at the level of the internal ring and is pushed into the abdominal cavity with palpation (“peeping testis”), thereby making it non-palpable (Fig. 8.1). With this finding, a conventional orchiopexy is often successful. The third scenario is that the testis resides in an intra-abdominal position and is not palpable for this reason. Testes in an intra-abdominal position usually cannot be brought into the scrotum with a standard orchiopexy.

Algorithm for Management

At the initial outpatient evaluation, a relaxed setting is important to allow the examiner to palpate the scrotum and inguinal canal. Often a frog-leg position is useful for an accurate examination. Once it is determined that one or both testes are not palpable, the patient is scheduled for diagnostic laparoscopy for clarification of the previously mentioned three possible scenarios.⁶ An algorithm for management is shown in Figure 8.2. In discussion with the family, these three scenarios should be discussed. If the testicular vessels clearly end blindly prior to entering a closed internal ring, then inguinal exploration is not required (Figs. 8.3 and 8.4). If the testicular vessels enter either a closed or open internal ring, then inguinal exploration is necessary to determine the characteristics of the testis. If the internal ring is open and a patent processus vaginalis is present, then orchiopexy may be possible depending on the status of the testis. However, if the internal ring is closed and no patent processus vaginalis exists, then in utero torsion has likely occurred in the inguinal canal and orchiopexy will usually not be possible. In either event, inguinal exploration is required under the same anesthesia to remove the testicular remnant or perform orchiopexy. The third possibility is the finding of an intra-abdominal testis (Fig. 8.5). With this information either a one-stage or two-stage Fowler-Stephens procedure will likely be required. The first or single stage can be performed under the same anesthesia and the surgeon should be prepared for this possibility.

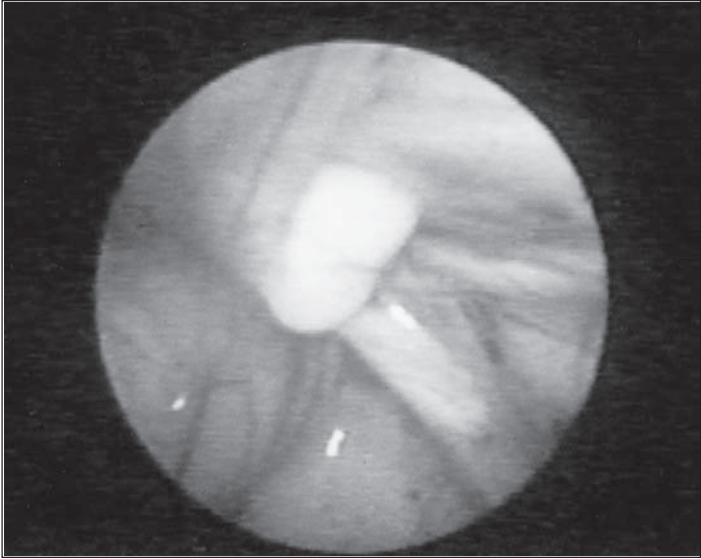


Figure 8.1. This boy has a “peeping” testis. This term refers to a testis that is located on the inguinal side of a patent processus vaginalis and is pushed into the abdominal cavity with palpation thereby making it non-palpable. Orchiopexy can be performed in many of these children using a conventional inguinal approach. However, in selected cases, a laparoscopic orchiopexy is required.

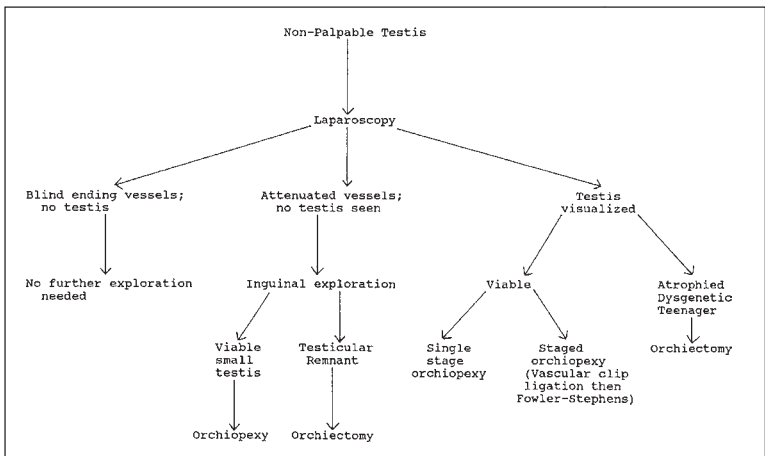


Figure 8.2. This algorithm depicts management of a boy with a non-palpable testis depending on the findings at laparoscopy.



Figure 8.3. In this 6-month-old boy with a non-palpable left testis, diagnostic laparoscopy through the umbilicus reveals a blind-ending vas deferens (solid arrow) and testicular vessels. These structures terminate at a considerable distance from the internal - and inferior epigastric vessels (open arrow). Retroperitoneal in utero torsion has occurred in this boy. Inguinal exploration is not required in this situation.

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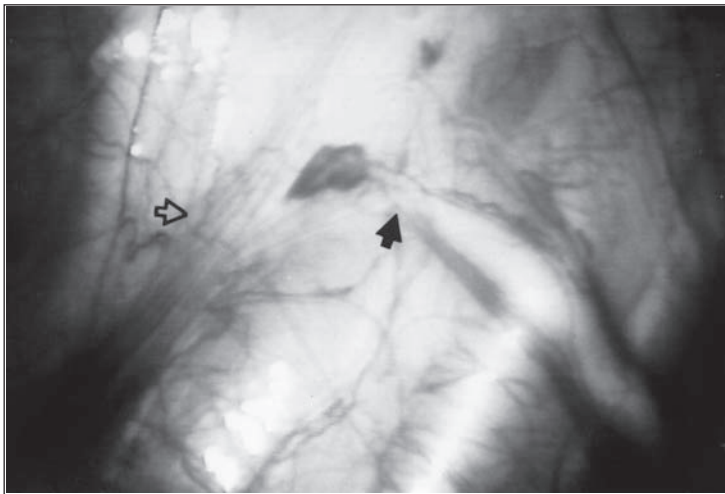
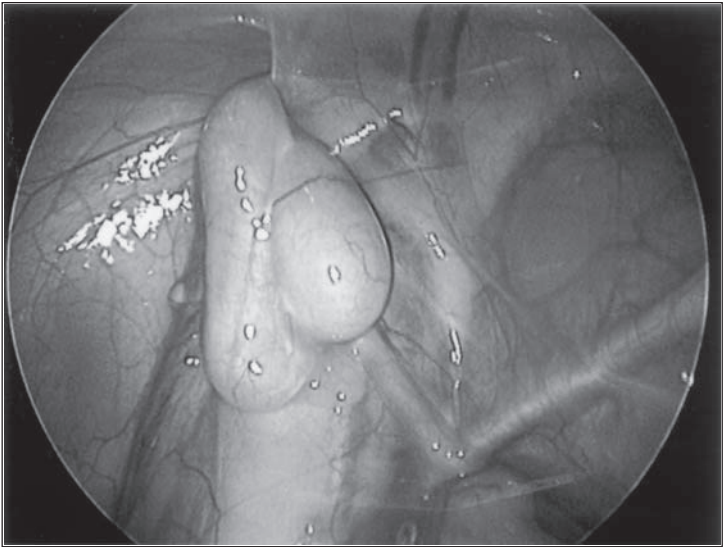


Figure 8.4. A closer inspection of the blind ending structures from Figure 8.3 demonstrates clearly the terminal portion of the vas deferens (solid arrow) and testicular vessels (open arrow).



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Figure 8.5. In this 10-month-old boy, a non-palpable left testis is visualized in an intra-abdominal location. Testicular vessels are not of sufficient length to reach into the scrotum using the conventional inguinal approach. Therefore, a two-stage Fowler-Stephens is employed in this patient.

Technique

Following induction of general endo-tracheal anesthesia, the bladder is emptied either with a Credé maneuver or intermittent catheterization to improve visualization of the pelvic structures. The scrotum and inguinal canal are examined once again to ensure that the testis is not palpable. Assuming that it remains non-palpable, the patient is positioned in a slightly frog-leg position and the abdomen and scrotum prepped and draped in a sterile fashion. A 4 mm incision is made in the center of the umbilicus and the umbilical fascia incised. Using this open technique, a blunt tipped reusable cannula is gently introduced into the abdominal cavity and pneumoperitoneum established to a pressure of 12 to 15 mm Hg. Diagnostic laparoscopy is performed with a 0° telescope and the findings noted. As previously mentioned, if the testicular vessels end blindly in the retroperitoneum and clearly do not enter a closed internal ring, no further management is required (Figs. 8.3 and 8.4). If the testicular vessels appear to be of normal size and enter a closed or open internal ring, then the umbilical fascial defect and skin are closed and inguinal exploration performed as previously mentioned. If an intra-abdominal testis is visualized, a decision is made to perform either a one-stage or two-stage Fowler-Stephens procedure. If a two-stage procedure is planned, then ligation and division of the testicular vessels proximal or cephalad to the testis is required, followed by a 6-9 month period of time to allow augmentation of the secondary collateral vasculature to the testis. This ligation and division can be performed either with endoscopic cautery (Fig. 8.6),

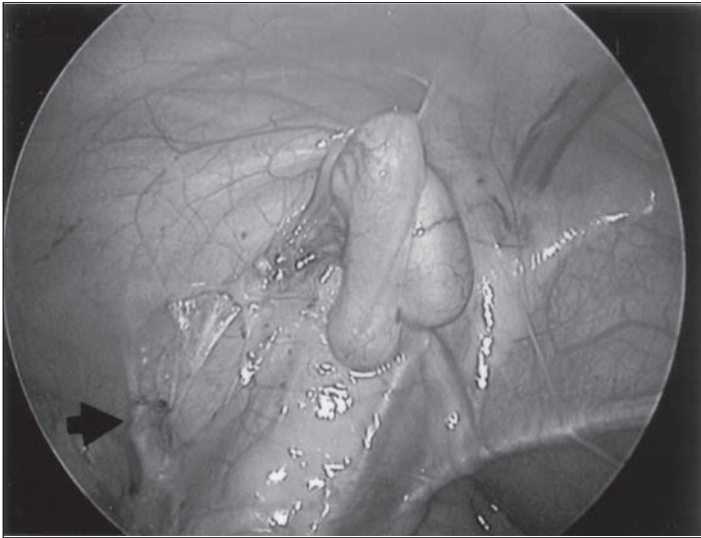


Figure 8.6. This photograph depicts ligation and division of the testicular vessels using the electric cautery in the patient initially referenced in Figure 8.5. The proximal end of the divided testicular vessels is marked (arrow). Six to nine months later, this patient will return to the operating room for the second-stage of a planned two-stage Fowler-Stephens orchiopexy.

endoscopic laser (KTP) or endoscopic clips (Fig. 8.7). If a one-stage procedure is performed, similar incisions are utilized as for the two-stage procedure. A 3 mm incision and port is placed in the left mid-epigastrium through which a 3 mm grasping forcep is introduced into the abdominal cavity. A 3 mm or 5 mm instrument is then placed in the right abdomen below the horizontal plane of the umbilicus (Fig. 8.8). This is the main operating port. If endoscopic clips are to be utilized, the 5 mm endoscopic clip applicator can be introduced through this port. However, if 3 mm cautery or the 400u KTP laser fiber are employed, this port can be 3 mm in size. The peritoneum overlying the testicular vessels approximately 2 cm cephalad to the testicle is incised. The testicular vessels are then either coagulated with the cautery or laser or secured with the 5 mm endoscopic clip applicator and divided. If the two-staged approach is used, nothing further is performed at this time. However, if a single stage laparoscopic orchiopexy is appropriate, the peritoneum overlying the iliac vessels is gently incised with either scissors or the cautery to the mid-line of the pelvis. This is accomplished taking great care to stay away from the collateral vasculature arising from the pelvis around the vas deferens and traversing towards the testis. Laterally, the peritoneum is also incised to the internal ring. Using a combination of blunt and sharp dissection, the peritoneum from these initial incisions is swept toward the pelvis.

At this point, a 10 mm incision is made in the scrotum and soft tissue dissection carried to the level of the pubic tubercle. A Veress needle with a radially expanding

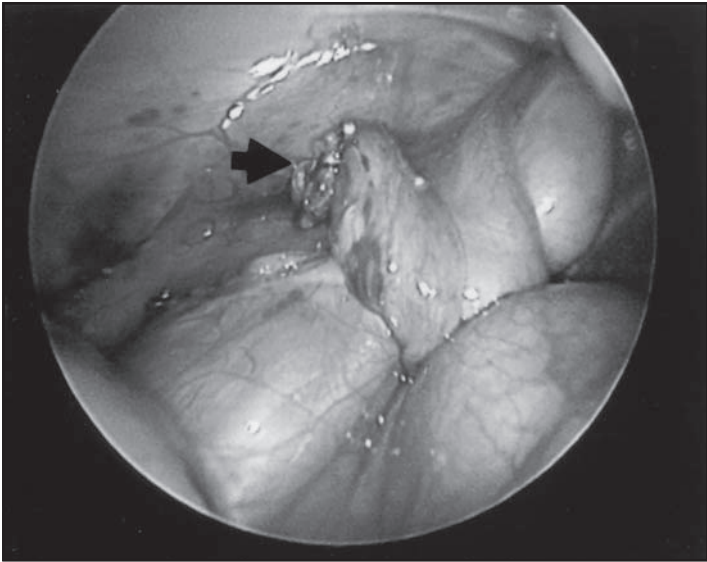


Figure 8.7. In this patient with an intraabdominal left testis, ligation and division of the testicular vessels is accomplished using the endoscopic clip applicator. Notice the clips on the distal portion of the divided testicular vessels (arrow).

sheath (Innerdyne, Sunnyvale, CA) is then introduced through the scrotal incision, over the pubic tubercle and into the peritoneal cavity under direct vision from the telescope in the umbilicus. The Veress needle is removed and a 10 mm blunt tipped cannula is inserted through the expandable sheath. In this fashion, a tunnel is created through which the testicle can be transposed from its intra-abdominal location into the scrotum. An atraumatic grasping forcep is introduced through the 10 mm cannula and the peri-testicular tissue secured. The grasping forcep and cannula are then withdrawn bringing the testis into the scrotum where it is secured with 3-0 suture. Usually, there is very little tension on the transplanted testis because of the adequate length of the vas deferens and collateral vasculature. Re-inspection of the abdominal dissection confirms intact hemostasis. The patent processus vaginalis can be sutured endoscopically. Having secured the testis to the scrotum, the scrotal incision is closed followed by approximation of the umbilical fascia and skin. The other two incisions are also secured as well and sterile dressings applied.

Teenagers

For teenagers with an intra-abdominal testis, orchiectomy is usually indicated as the testis likely will not be functioning and because of the risk of subsequent malignant deterioration. Orchiectomy can be performed utilizing the same incisions. The testicular vessels and vas deferens are divided either with cautery or clips and the testis mobilized. It can then be delivered through the 5 mm right lower abdominal incision or the umbilical incision can be enlarged to deliver a larger specimen.

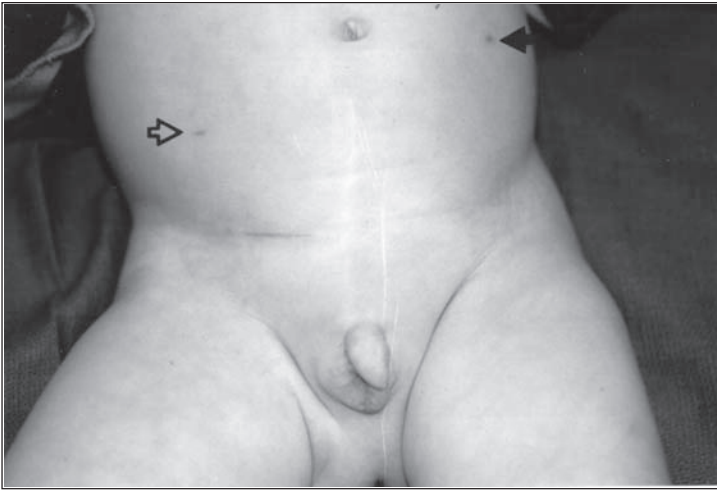


Figure 8.8. This young boy initially presented with a palpable undescended testis in the right inguinal canal and a non-palpable left testis. He underwent conventional right orchiopexy through a right inguinal approach. Due to the very thin right patent processus vaginalis, laparoscopy through the sac was felt hazardous. For this reason, he underwent laparoscopy through the umbilicus to assess for the presence or absence of a non-palpable left testis. At laparoscopy, he was found to have an intra-abdominal testicle and underwent coagulation of the left testicular vessels. Notice a 3 mm incision in the left mid-abdomen (solid arrow) and a 3 mm incision (open arrow) in the right lower abdomen, slightly above the right inguinal crease. In six months, he will be returned to the operating room for the second stage of a two-stage Fowler-Stephens procedure to locate the left testicle in the left hemi-scrotum.

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Bilateral Disease

If a boy presents with bilateral non-palpable testes, diagnostic laparoscopy can be utilized to document the presence of one or both testes. If both testes are noted to be intra-abdominal, a staged approach is recommended with completion of the orchiopexy on the one side followed by orchiopexy on the contralateral side 6 to 9 months later. A similar plan is followed if a boy has a palpable testis on one side and a non-palpable testis on the other. In that situation, following completion of the conventional orchiopexy on one side, diagnostic laparoscopy is performed, usually through an umbilical approach. If a non-palpable testis is noted on the contralateral side, then ligation of the testicular vessels is performed at the first stage followed 6 to 9 months later by the second stage Fowler-Stephens procedure (Fig. 8.8). The rationale for a two-staged approach for the intra-abdominal testis in this setting is to be certain that the first testis brought into the scrotum has not developed any complications or atrophy prior to performing the operation for the second testis.

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Laparoscopic Appendectomy in Children

Kelly A. Kogut

Appendicitis is the most common surgical emergency in children. Laparoscopic appendectomy is generally one of the simpler laparoscopic procedures and does not require specialized laparoscopic instrumentation beyond that which is usually readily available. Thus for the novice laparoscopic surgeon, laparoscopic appendectomy is one of the best ways to gain experience and confidence.

Indications

In general, the indications for the laparoscopic approach to appendectomy are the same as the open approach. However, there remains some controversy regarding the laparoscopic approach for appendectomy in children. Because the open approach for most children requires a very small incision and a short hospital stay and has a low rate of complication, it is difficult to measure any clear benefit of the laparoscopic over the open approach. Additionally, there may be an increased cost to the laparoscopic approach, which can be minimized by the use of reusable instruments. Operative times may be longer during the first part of the learning curve, but with experience do not significantly differ from the open approach.

The use of the laparoscopic approach for perforated appendicitis is controversial, and some authors believe that it is contraindicated in cases of known perforation. In Memphis, where children with perforated appendicitis are initially treated with antibiotics, the laparoscopic approach is used successfully for interval appendectomy, performed 8-12 weeks after the perforation. In this situation, the appendix may appear almost normal, or there may be a few adhesions easily handled by the laparoscopic approach.

The advantages of the laparoscopic approach for the patient include lower chances of wound infection, decreased postoperative pain, and faster return to unrestricted activity. There is also improved cosmesis.

One of the major advantages of the laparoscopic approach for the surgeon is the ability to inspect the entire abdominal cavity. This is helpful in situations where the diagnosis is uncertain or when the appendix is not found to be inflamed and a search for other potential pathology is indicated. The ability to thoroughly inspect the ovaries in female patients to exclude this source of pathology is an important advantage of the laparoscopic approach.

Anesthesia and Patient Preparation

General anesthesia is required. A nasogastric tube is placed to decompress the stomach, which is often full. A Foley catheter is placed to decompress the bladder, minimizing the risk of bladder injury during cannula placement. Both catheters are

removed at the end of the operative procedure. The patient is positioned supine and securely strapped to the operating room table.

Operating Room Set Up

Appendectomies are not often scheduled cases, and thus are frequently staffed by operating room personnel less familiar with the set up of the laparoscopic equipment. The surgeon must be experienced at setting up the case and trouble-shooting the equipment.

One tower holding the CO₂ tank, alarmed insufflator, light source and monitor helps keep instrument clutter in OR to a minimum. The tower is optimally placed near the patient's right ankle. The surgeon and assistant stand on the patient's left side, the mayo stand and scrub nurse are on the patient's right.

Technique

There are many permutations on the theme, and our preferred technique is described here.

The abdominal wall is prepped from pubis to supraumbilical area. A 12 mm port (reposable Step system, Interdyne, Inc., Salt Lake City, UT) is placed through an umbilical cut-down (open technique), and CO₂ pneumoperitoneum is established at a maximum pressure of 15 mm Hg. Two 5 mm ports (reposable Step system, Interdyne, Inc., Salt Lake City, UT) are then placed under laparoscopic visual control. The first is placed laterally in the left lower quadrant, and the second is suprapubic in the midline, taking care to avoid injury to the bladder. The preperitoneal space in the suprapubic location is quite loose, and many times placement of the tip of the cannula into the peritoneal cavity is difficult. Providing counterpressure with an open grasper from within the peritoneal cavity while placing the Veress needle and radially-expanding sheath facilitates entrance into the peritoneal cavity.

Exposure of the appendix is best accomplished with the patient in a slight Trendelenburg position and with the operating room table rotated toward the patient's left allowing the small bowel to fall away from the right lower quadrant. The 5 mm, 0° telescope is moved from the umbilical port to the left lower quadrant port, and is held by the assistant standing at the surgeon's left side. A 5-mm atraumatic grasper is introduced through the suprapubic port and is used to grasp the appendix approximately 1 cm from the base. A dissector placed through the umbilical port (12 mm port with 5 mm reducing cap) is used to create a window in the mesentery at the base of the appendix. The endoscopic linear stapler-cutter fit with 2.5 mm staples (vascular cartridge) fits through the 12 mm cannula at the umbilicus. The valved-cap can be unscrewed from the cannula sheath and the appendix removed without wound contamination. Replacement of the cap allows pneumoperitoneum to be re-established. If the appendix is too large to be retracted into the 12 mm cannula, it can be placed into an endoscopic bag. The bag is withdrawn via the umbilical incision, enlarged as necessary to retrieve the specimen.

The stapled mesoappendix and cecum are carefully inspected for hemostasis, and any debris remaining in the right lower quadrant or pelvis is suctioned and irrigated as needed. The cannulae are then vented to remove any remaining CO₂ pneumoperitoneum before removal.

The fascial wounds are closed with absorbable sutures, and the skin edges are reapproximated with Steri-strips (3-M Co.). The patients are allowed diet and activity as tolerated and are usually discharged home on the first postoperative day.

Conclusions

Laparoscopic appendectomy is safe and effective in children. Although controversial for children with perforated appendicitis, children undergoing laparoscopic appendectomy for acute appendicitis may enjoy many of the benefits of the less invasive approach. The laparoscopic approach is of particular benefit in a subset of children including those with an uncertain diagnosis, chronic abdominal pain, negative findings of appendicitis, adolescent females, and those requiring interval appendectomy after perforated appendicitis.

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Thoracoscopic Repair of Esophageal Atresia With or Without Tracheo-Esophageal Fistula

Thom E. Lobe

Introduction

Esophageal atresia, with or without tracheo-esophageal fistula (TEF), has long been recognized as one of the most technically challenging congenital anomalies we face as pediatric surgeons. Although the approach to the repair of esophageal atresia has evolved from transpleural to extrapleural in many centers, few changes from the originally described technique have occurred, and a standard posterolateral thoracotomy is still recommended by most. Not only does the classical thoracotomy present a major stress for the newborn, who is often premature, but also the extrapleural approach exposes the neonate to added time in the operating room, potentially exacerbating the stress response.¹ Over the course of the last decade, endoscopic techniques have been introduced to minimize stress in children who require invasive procedures.^{2,3} And, in the last few years, instrumentation suitable for newborns has been produced. Advancements in technology, therefore, have permitted the endoscopic repair of certain congenital anomalies, previously thought to be unapproachable by minimally invasive techniques.

Particularly challenging is the neonatal thorax which has essentially no expandability, unlike the abdominal wall. Further, open thoracotomy allows retraction of the right lung that is not as easily accomplished using closed techniques, while the latter also requires a means to exclude the right lung from ventilation.

We first reported the successful repair of isolated esophageal atresia (EA) using an endosurgical technique and more recently a similar approach to the repair of EA with TEF.^{4,5} These case reports confirmed the technical feasibility of thoracoscopic repair of EA with or without TEF. The world experience with this procedure now exceeds two dozen cases.

Methods

All babies were approached using the thoracoscopic techniques previously described.^{4,5} In brief, after the induction of general anesthesia and orotracheal intubation, a 3 French Fogarty balloon catheter is passed into the right mainstem bronchus to exclude ventilation to the right lung. Babies are then positioned prone, with the right of the patient elevated $\sim 60^\circ$ from the horizontal plane. A 3 mm trocar is placed in the fourth intercostal space along the posterior axillary line to admit a 30° telescope. A second 3 mm trocar is placed in the sixth intercostal space along the

mid-axillary line, and a 5 mm Interdyne trocar is then placed in the second intercostal space, also in the mid-axillary line. Gentle CO₂ insufflation is used to decompress the right lung, and the Fogarty balloon is then inflated to block its ventilation. A fourth port may be placed to retract the lung if ventilation to the right lung persists. Also, gentle insufflation of CO₂ to 4 mm Hg alone may be used to maintain continued decompression of the right lung without added instrumentation.

The pleura overlying the posterior mediastinum is incised, exposing the vagus nerve and azygous vein. The azygous vein is divided using Ligasure bipolar electrocautery (Valleylab, Boulder, CO) or a right-angled hook electrocautery. The proximal esophageal pouch is visualized upon manipulation of a Repogle tube and is mobilized to the thoracic inlet. By following the vagus nerve along its caudad extent, the distal esophageal pouch can be identified and is also mobilized. The fistula from the distal pouch to the membranous portion of the trachea is divided between 5 mm clips preserving as much length of esophagus as is possible. Absorbable 4-0 monofilament suture is used to approximate the two esophageal pouches. The ends are freshened for anastomosis, and the Repogle tube is advanced through the distal end into the stomach. Circumferential sutures are then placed sequentially using extracorporeal knot tying; each knot is then grasped to rotate the suture line for placement of the next stitch. Care is taken to ensure inclusion of mucosa with each suture. Fibrin glue can then be applied to reinforce the suture line if desired. A 12 French thoracostomy tube is inserted via the lowest trocar site, and the lung is re-expanded. All babies were studied with a barium swallow between 5 and 21 days postoperatively to exclude anastomotic leak. Each baby was then started on an oral diet and was advanced to goal feeds within 24 hours.

Results

To date, the experience with thoracoscopic repair of EA includes about two dozen neonates with and without TEF. Most babies having endoscopic esophageal reconstruction had a birth weight above 2 kilograms. Associated anomalies were identified in only a few patients, usually having mild cardiac defects consistent with the VACTERL syndrome. All babies are currently alive and well to the best of our knowledge.

No intraoperative complications were encountered, and recent operative times have ranged from 55 to 120 minutes. All babies tolerated isolated left lung ventilation without difficulty, irrespective of technique chosen to exclude the right lung (right mainstem Fogarty balloon inflation, compression using a fan retractor, or gentle continuous CO₂ insufflation). Successful completion of thoracoscopic esophageal reconstruction was possible in most of these babies. One procedure was converted to open technique because of a friable proximal pouch that contained the fistulous communication to the membranous portion of the trachea. This proximal TEF required ligation through a separate cervical incision.

Early postoperative complications were notable for chest tube drainage of a small volume of saliva in the occasional infant within the initial 72 hours. These showed spontaneous resolution of this drainage only a few days later. On subsequent esophagogram, neither baby showed evidence of leak. Also, no babies developed empyema or other infectious complications.

Late complications were appreciated in a few patients who, by the 6th postoperative week, required gentle bougienage to dilate mild strictures as noted on a routine delayed esophagram. Some of these babies were noted to have primary esophageal dyskinesia. No trend could be identified between those having mild salivary chest tube drainage and the later development of mild stricture. None of the babies to date has developed recurrent fistulization.

Discussion

A critical review of our experience using thoracoscopy to repair esophageal atresia, with or without distal TEF, suggests that this approach offers several advantages over the classic, open operation. All advantages hinge on avoidance of the time-honored thoracotomy, while the remaining steps of our technique employ the same philosophy as the traditional procedure.

Few patient populations are as vulnerable to physiologic stressors as the neonate, particularly if affected by multiple anomalies as is often the case with esophageal atresia. Markers of systemic inflammation indeed have been shown to decrease when endoscopic techniques are utilized.¹ The closed technique further reduces metabolic stress by minimizing exposure of the central vital organs to the cold temperatures of the operating room. We firmly believe that thoracoscopy confers less physiologic stress on the newborn.

Long-term follow up of patients having thoracotomy in the neonatal period has further shown a potential for problems with musculoskeletal development of the thoracic cage.⁶⁻¹³ Not only is the postoperative scar superficially disfiguring, but also a significant risk for developing scoliosis and shoulder girdle weakness is incurred. Thoracoscopy certainly minimizes trauma to the thoracic wall and therefore results in less potential for alterations of normal healing. Additionally, the nonmuscle sparing thoracotomy is widely recognized by surgeons as one of the most painful incisions. Although we have yet to assess formally the pain response in our series of patients, these babies appear to have less discomfort as measured and documented by the bedside nurses.

Critics may view the required transpleural approach of the thoroscopic technique as a disadvantage, potentially increasing the risk for empyema should a leak occur. However, one advantage not anticipated when developing our endoscopic technique is the clear improvement in visualization of the esophageal pouches and the respective mucosal layers. One of the critical features in performing a secure esophageal reconstruction is incorporation of the mucosa with each suture. The magnification provided by the telescope offers exceptional identification of this layer and reassurance for an anastomosis of the highest integrity. As a result, although we had a small number of babies drain saliva from their chest tubes in the early postoperative period, none had evidence for anastomotic leak when studied by routine esophagography a few days later, nor did any develop empyema. Neither of these babies had a delay in initiating oral feeds. Furthermore, mild stricture formation has been documented in only three of our babies to date, and each has responded to gentle bougienage. Skeptics also have questioned whether neonates can tolerate insufflation of CO₂ within the thoracic cavity in order to decompress the right lung. Alterations of perfusion have not been realized, as adequate lung deflation with 4-6

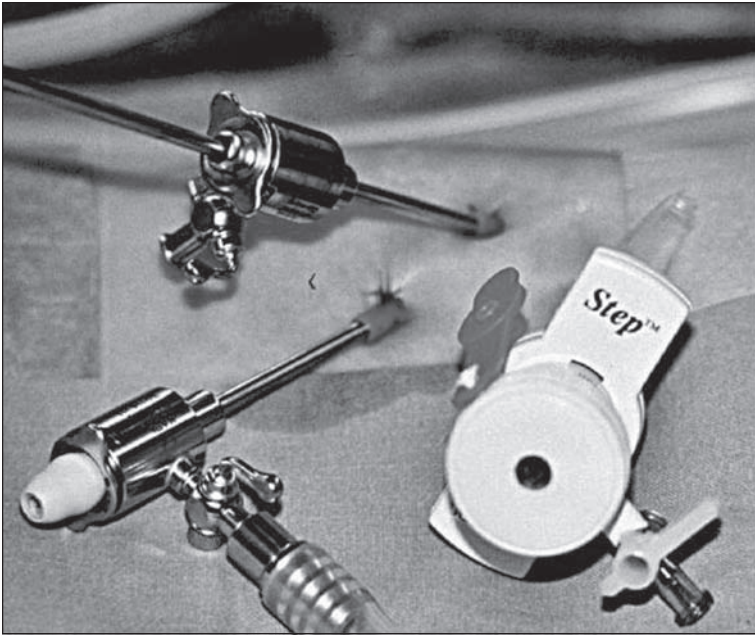


Figure 10.1. Basic set-up for thoracoscopic repair of esophageal atresia, with or without a tracheo-esophageal fistula. The patient is positioned with the right side up, tilted slightly anteriorly at about 45 degrees. Three ports are used. One three millimeter port is placed posteriorly between the posterior and mid-axillary lines and is used for the telescope. Another three millimeter port is placed inferior to this in the mid- to anterior axillary line for the left hand instrument. A five millimeter port is used superiorly for passage of the sutures.

mm Hg is achieved in the absence of hemodynamic compromise. Because all knots are tied extracorporeally, spatial constraints are minimized, and the learning curve is shortened, requiring only a sound understanding of the technique as outlined and a modest proficiency in endoscopic skills, principally suture placement.

In conclusion, the thoracoscopic approach to the repair of esophageal atresia with or without distal TEF offers real advantages over the classic technique that requires open thoracotomy. Specifically, babies are spared the perioperative stressors, pain, and long-term sequelae of thoracotomy at no compromise in anastomotic integrity or safety to the baby. Because the basic philosophy behind closed esophageal reconstruction remains the same as with the open procedure, the learning curve is not greatly increased. As a result, with minimal extra training, all pediatric surgeons competent in the use of endoscopic techniques should be able to master this technique rapidly.

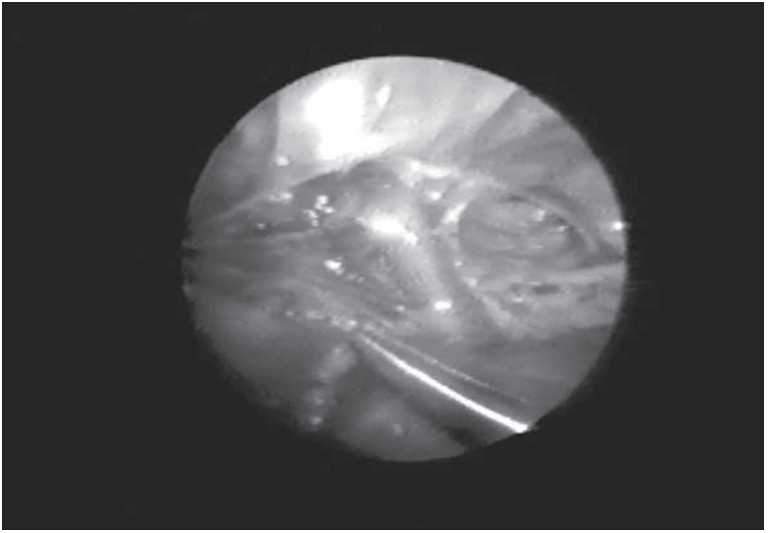


Figure 10.2. View of the Azygous vein that is usually divided to expose the esophagus.

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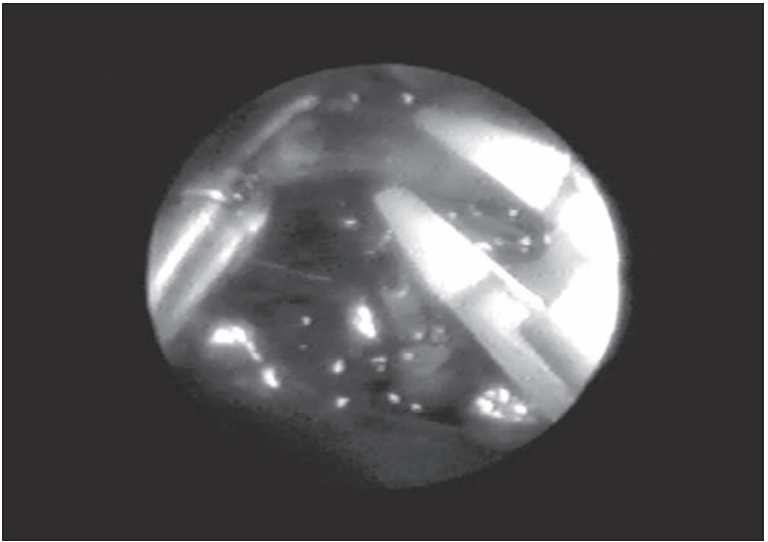


Figure 10.3. Endoscopic clip placed across the tracheo-esophageal fistula.

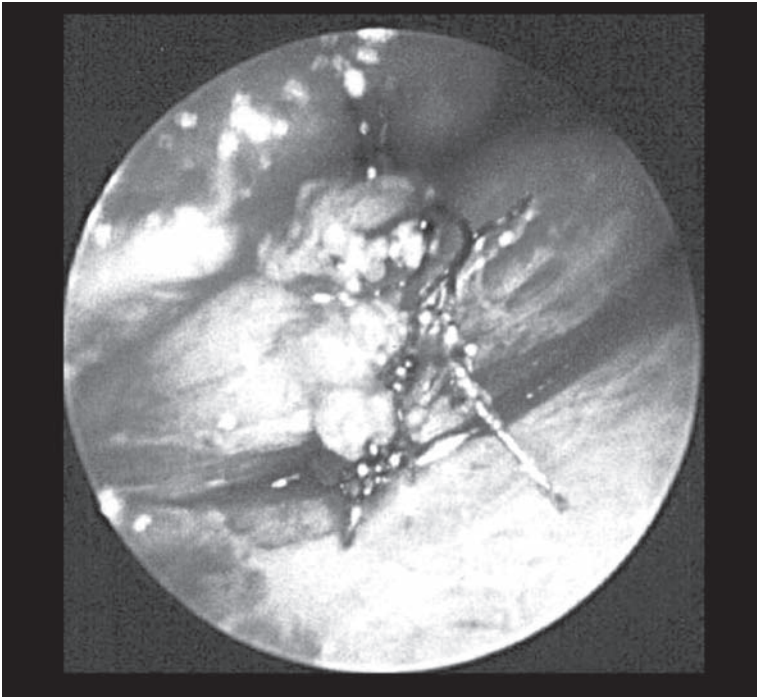


Figure 10.4. Completed esophago-esophagostomy.

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Figure 10.5. Post-operative esophagram after a thoracoscopic esophago-esophagostomy.

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Laparoscopic Cholecystectomy

George W. Holcomb, III

In 1989, Reddick and Olsen in the United States and Dubois, et al in France published the first reports of the utilization of laparoscopy for cholecystectomy.^{1,2} Soon thereafter, the technique of laparoscopic cholecystectomy became routine and the standard of care. In 1991 and 1993 the initial descriptions of laparoscopic cholecystectomy in children were published.³⁻⁷ These reports described an initial experience of less than 10 patients at each center and demonstrated that the operation could be performed safely and effectively in pediatric patients. Although the application of laparoscopy for other conditions in children was slow to evolve, most pediatric surgeons began to apply this technique for cholecystectomy.

Historically, children have required cholecystectomy for cholelithiasis due to hemolytic disease. However, over the past 20 years, there has been a changing pattern of disease as more and more patients have been diagnosed with idiopathic cholelithiasis rather than cholelithiasis due to spherocytosis or sickle cell disease. This increased awareness of children with cholelithiasis may be due to an increase in the development of gallstones, but may also be due to increased documentation with the widespread use of ultrasound for evaluation of children with abdominal pain.

Laparoscopic Cholecystectomy

Once the diagnosis of cholelithiasis or, occasionally, biliary dyskinesia has been made, the infant or child is scheduled for an elective procedure. Following induction of general endotracheal anesthesia, an orogastric tube is introduced for gastric decompression and the bladder is emptied with a Credé maneuver in younger children. In older children, a urinary catheter is usually not required due to the brevity of the procedure.

The patient is prepped and draped widely as for an open operation. The safest technique for placement of the initial cannula is direct incision of the umbilical skin and fascia with gentle introduction of a Veress needle and accompanying sheath into the abdominal cavity (Innerdyne, Sunnyvale, CA).

Following establishment of a pneumoperitoneum, the Veress needle is removed and a 5 mm or 10 mm blunt cannula introduced into the abdominal cavity through the sheath. Diagnostic laparoscopy is then accomplished followed by introduction of accessory ports.

Infants

In children in less than 2 years of age, laparoscopic cholecystectomy can be readily accomplished.⁸ However, placement of the auxiliary ports is different from the older patients in that an adequate working space must be created. Therefore, following

placement of the 5 mm umbilical cannula, a 3 mm or 5 mm cannula is positioned at the level of the right inguinal crease, a 3 mm cannula is introduced laterally near the right flank and a 5 mm port situated in the left mid-epigastrium. (Fig. 11.1) As

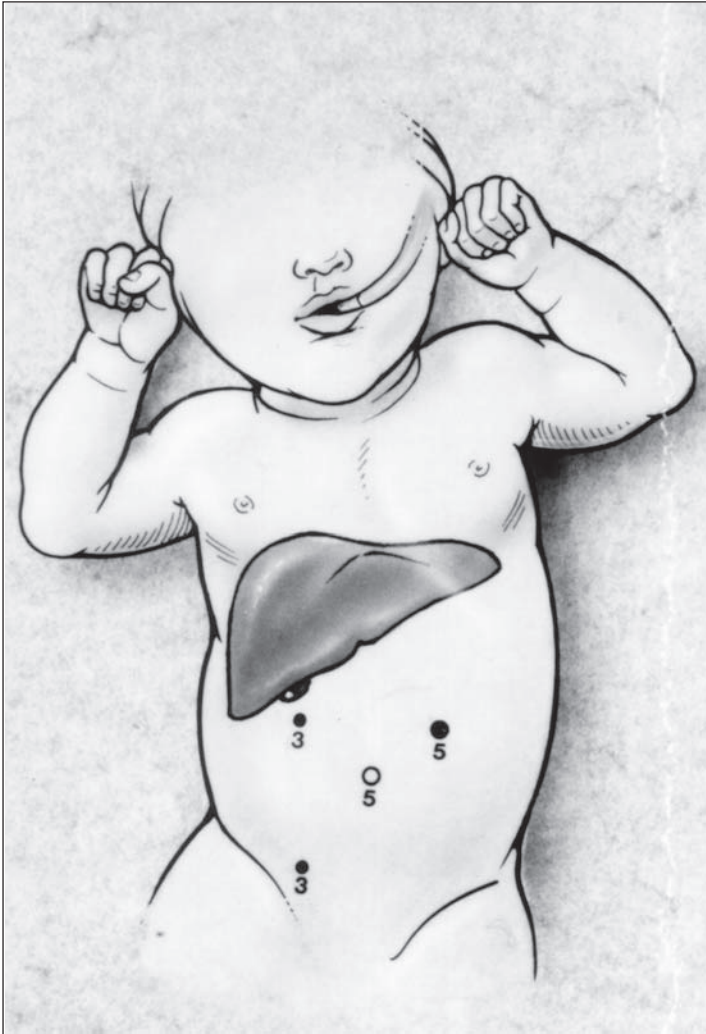


Figure 11.1. This artist's rendering depicts the port placements for an infant. It is important to widely space the cannulas so as to create an adequate intra-abdominal working space in a small patient. The most inferior right port can be placed in the inguinal crease region for cosmesis. Moreover, the epigastric port should be placed to the left of the midline for an efficient operation.

most gallbladders in the age group can be extracted through a 5 mm umbilical incision, a 5 mm umbilical port is usually sufficient.

Children Ages 2-12

The positioning of cannulas in this age group needs to be individualized according to the body habitus. For smaller children, the right lower port can be placed near the inguinal crease but should be closer to the level of the umbilicus in the larger patients. A 3 mm cannula positioned laterally in the right abdomen is usually sufficient in this age patient. The umbilical port should usually be 10 mm as the gallbladders are larger and require a larger umbilical incision for extraction. A 5 mm cannula is placed in the medial aspect of the left mid-epigastrium as a 5 mm endoscopic clip is usually sufficient for ligation of the cystic duct in this age patient. (Fig. 11.2)

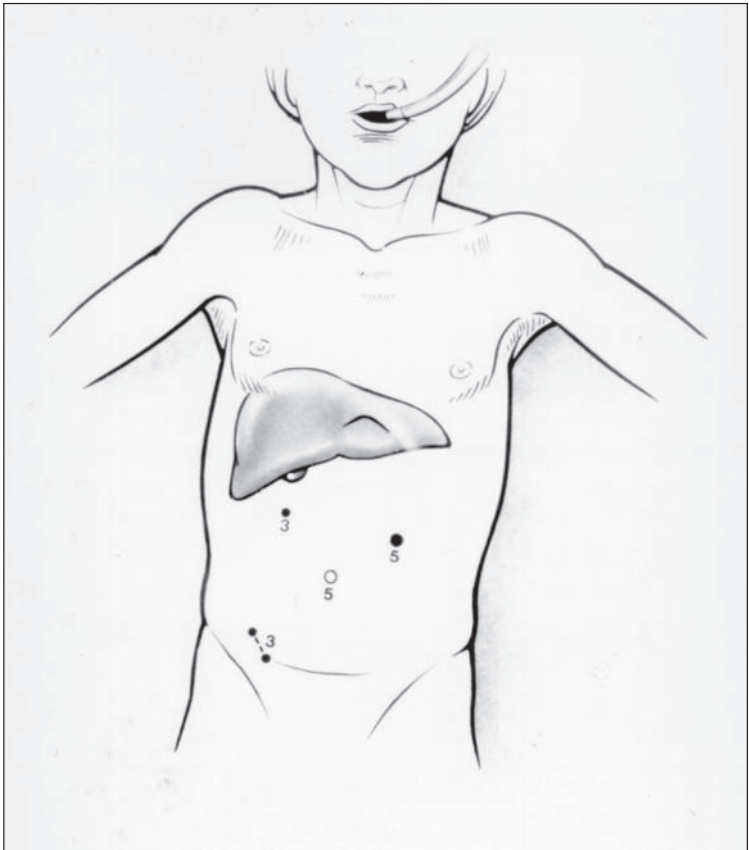


Figure 11.2. This diagram demonstrates the location of the ports for laparoscopic cholecystectomy in children between the ages of 3 and 12. The most inferior port should be positioned cephalad in the older child.

Teenagers

In these older pediatric patients, placement of the ports mirrors that of the adult patient with the right lower cannula being situated at the level of the umbilicus and the epigastric cannula positioned either just to the left or right of the midline. The umbilical port should be 10 mm and the epigastric port can either be 5 mm or 10 mm depending on the size of the endoscopic clip required to ligate the cystic duct. The other two accessory cannulas can be either 3 mm or 5 mm. (Fig. 11.3)

Technique

Following introduction of these accessory ports, the patient is rotated to the left and into reverse Trendelenburg to allow the colon to fall away from the gallbladder. A grasping forcep is introduced through the right lower cannula and the dome of the gallbladder secured. It is rotated superiorly and ventrally over the liver which exposes the triangle of Calot. A grasping forcep is then placed through the right lateral port and the infundibulum is retracted laterally, creating a 90° angle between

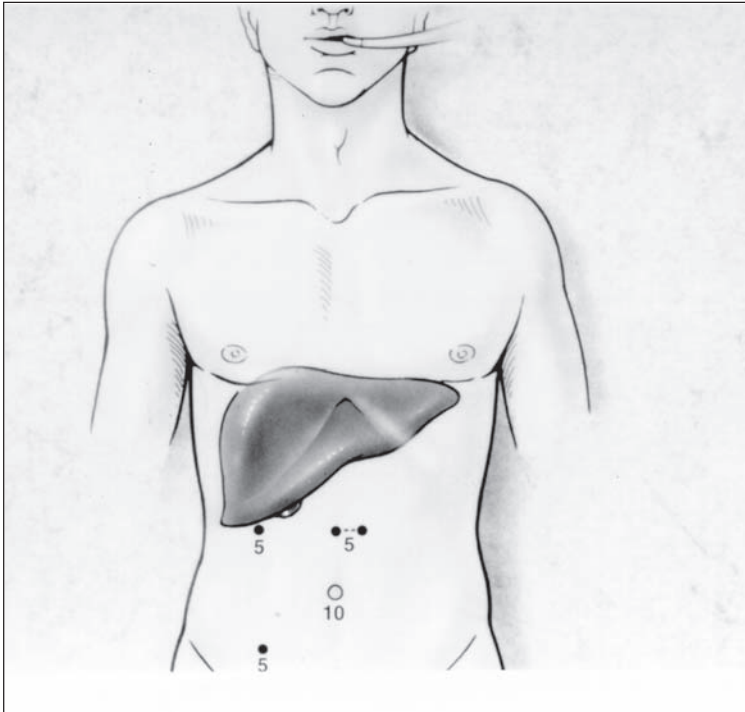


Figure 11.3. In the teenager, the location of the ports mirrors that in adult. The epigastric cannula can be situated either to the right or the left of the midline. In addition, a 10 mm umbilical port is usually required to extract the gallbladders in these older children.

the cystic and the common bile ducts to prevent misidentification of these two structures. (Fig. 11.4) Through the primary working port in the epigastrium, a scissor with attached cautery is used to lyse adhesions which may have developed from inflammation. The cystic duct is then identified and skeletonized. It is at this point that cholangiography can be performed if desired.

Cholangiography

The primary indication for cholangiography in children is correct identification of the cystic and common bile ducts. Most children have had a recent preoperative ultrasound which has documented the cholelithiasis and the likely absence of common bile duct dilatation or stones. Therefore, an intraoperative cholangiogram to document the absence of stones is rarely needed. However, injury to the common bile duct can be such a significant complication that it is imperative to identify correctly the anatomy of the cystic and common bile ducts to prevent injury to the common bile duct. For this reason, if the anatomy is unclear, cholangiography should be performed.

There are several techniques possible for cholangiography. In addition to lateral incision of the cystic duct and introduction of a small cholangi catheter into the cystic duct, percutaneous introduction of a needle into the gallbladder with



Figure 11.4. It is important to retract the infundibulum laterally to create a 90° angle between the cystic and common ducts to prevent misidentification of these two structures.

subsequent instillation of dye is also possible. I prefer to use the Kumar Pre-view cholangiography clamp (Nashville Surgical Instruments, Springfield, TN) technique in which an atraumatic clamp is placed through one of the ports (usually the inferior one) and positioned across the infundibulum of the gallbladder.⁹ Through a side channel in the clamp, a cholangiography catheter with a 19 g needle is introduced into the infundibulum proximal to the occlusive clamp. (Fig. 11.5) Contrast is then instilled into the infundibulum and cystic duct. (Fig. 11.6) This is easily accomplished in most patients. However, if there is a stone at the junction of the cystic duct and infundibulum, the cholangiogram will not be successful. Also, if there is significant inflammation of the gallbladder due to cholecystitis, the cholangiogram may also be unsuccessful. The atraumatic clamp is placed across the infundibulum distal to the needle to prevent filling of the gallbladder with dye. Moreover, if the gallbladder is distended and tense, it can be decompressed with the catheter and needle as well.

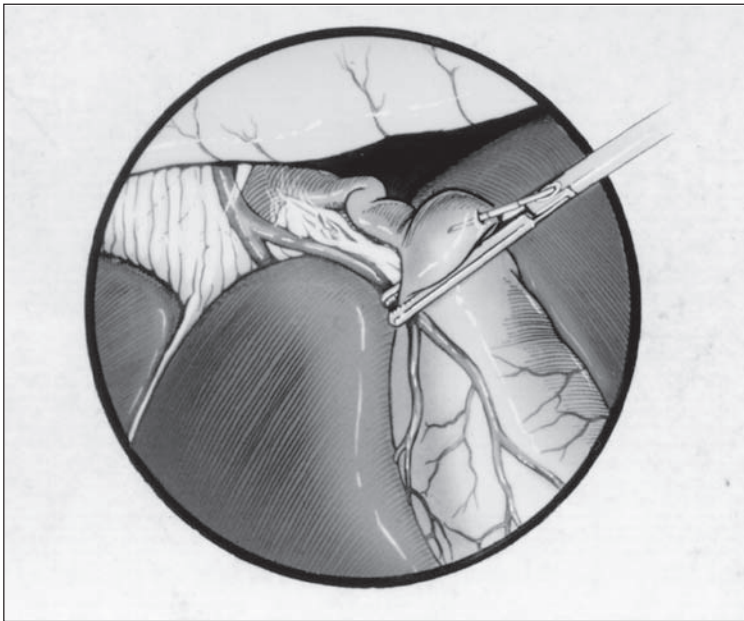


Figure 11.5. The Kumar pre-view cholangiography clamp technique is optimal in pediatric patients. An atraumatic clamp is placed across the infundibulum of the gallbladder. Through the side arm in the clamp, a 19 gauge needle attached to a cholangiography catheter is directly introduced into the infundibulum proximal to the occlusive clamp. With this technique, cannulation of a small cystic duct is not required.

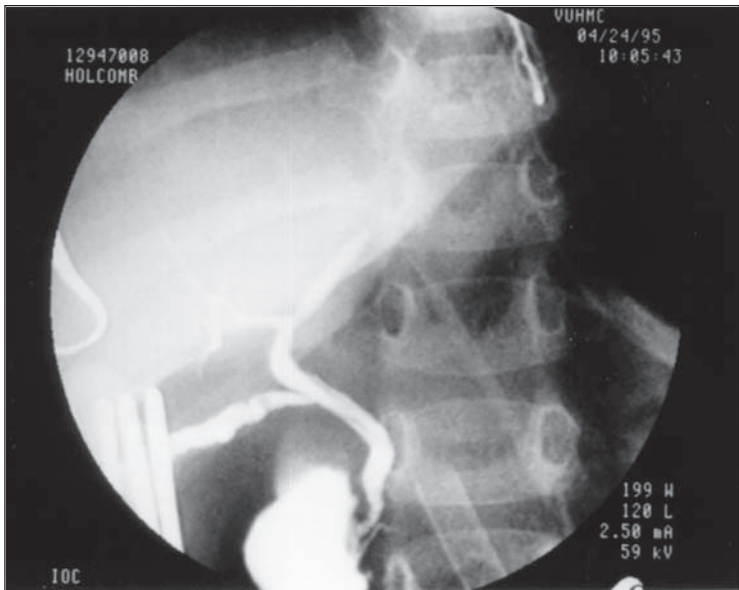


Figure 11.6. In this 2 1/2-year old patient, cholangiography is easily performed. The cystic duct is seen entering the common duct with passage of dye into the duodenum without evidence of obstruction. In addition, the correct anatomy is confirmed.

Completion of Cholecystectomy

If cholangiography has been performed, the cholangiocatheter is removed. If it has not been performed, then ligation and division of the cystic duct is accomplished. The two endoscopic clips are placed on the cystic duct near, but not at, the junction of the cystic and common bile ducts. Another clip is placed at the junction of the cystic duct and infundibulum. The cystic duct is divided leaving two clips on the cystic duct stump. In a similar fashion, the cystic artery is also doubly clipped and divided. (Fig. 11.7) The gallbladder is then dissected from the liver bed in a retrograde fashion using the cautery. Although I utilize the hook cautery, others prefer the spatula cautery. (Fig. 11.8) Prior to almost completely detaching the gallbladder from the liver bed, the area of dissection is inspected for hemostasis. Once hemostasis is assured, the gallbladder is completely freed and extracted through the umbilicus. In younger patients, it is often possible to deliver the gallbladder through the cannula. However, in older patients, and especially those with an inflamed gallbladder, it is usually necessary to remove the umbilical cannula and deliver the gallbladder through the fascial incision. Occasionally, it is necessary to incise further the fascial opening to extract a large and inflamed specimen.

After the gallbladder has been removed, the area of dissection is again inspected to ensure hemostasis. Once hemostasis is assured, the ports are removed and Bupivacaine is instilled into the incisions for postoperative analgesia. The umbilicus is closed with a 2-0 or 3-0 absorbable suture depending on the patient's size. The

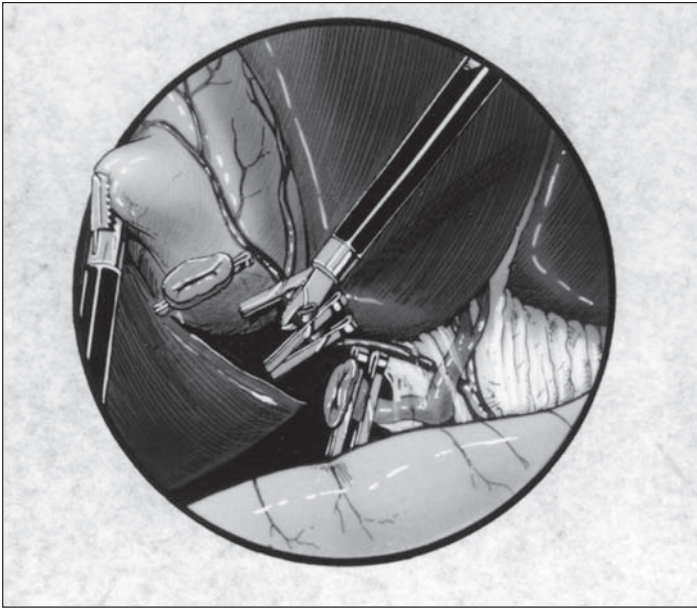


Figure 11.7. The cystic duct has been doubly clipped with 2 clips visualized on the cystic duct stump. In a similar fashion, the cystic artery is being clipped and divided.

umbilical skin is closed with 4-0 or 5-0 plain catgut suture placed in an interrupted fashion. The other incisions are secured with subcutaneous 5-0 absorbable suture. Sterile dressings are applied and anesthesia is terminated.

The patients are usually discharged the next day. If the operation was performed early in the day, an occasional patient may be ready for discharge the evening of the procedure. The patients are evaluated in two weeks and thereafter as needed. Routine laboratory studies or ultrasounds are not performed unless indicated.

Choledocholithiasis

The management of children with choledocholithiasis is complex, as the management decisions are dependent on the availability of an experienced endoscopist for endoscopic retrograde cholangiopancreatography (ERCP) and sphincterotomy. For this reason, I prefer to know preoperatively whether or not such an individual is available and if stones are definitely located in the common bile duct.^{10,11} For patients with documented or suspected choledocholithiasis on ultrasonography, I prefer to ask an endoscopist to perform ERCP, sphincterotomy and extraction of the stones, if they are documented. The rationale for this is that, at the time of laparoscopic cholecystectomy 24 hours later, I know whether or not a laparoscopic choledochal exploration will be required. This approach is somewhat different than in adults in which there is almost routine availability of such an endoscopist. Therefore, many adult laparoscopic surgeons will complete the laparoscopic cholecystectomy and have

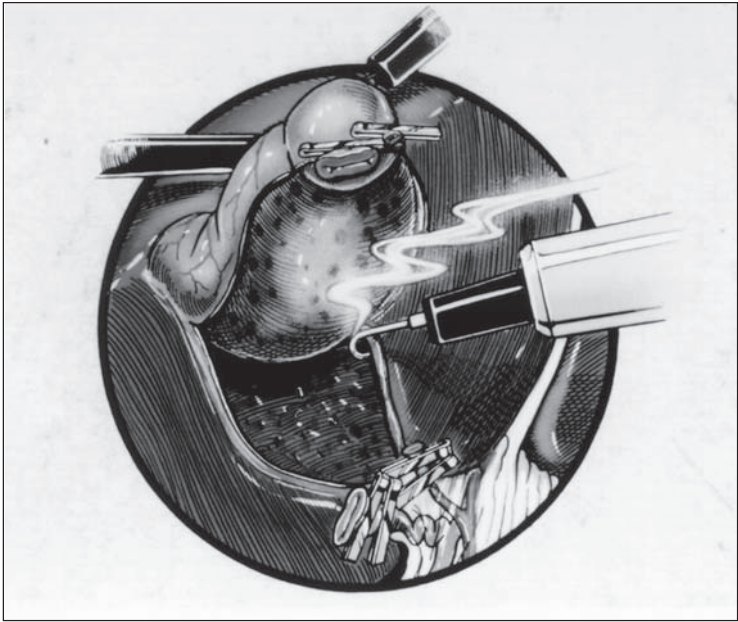


Figure 11.8. The gallbladder is dissected free from the liver bed using the hook cautery.

their endoscopic colleague perform an ERCP with extraction of the stones the following day. In children, however, such endoscopic availability is not as routine and the surgeon needs to know whether or not open or laparoscopic choledochal exploration will be necessary at the time of the cholecystectomy.

If stones are not suspected preoperatively, but noted at the time of cholangiography, then choledochal exploration is not advisable if an experienced endoscopist is available. The disadvantage of not performing the choledochal exploration and relying on the endoscopist to extract the stones is that the child will require another operation if the endoscopist is not successful in extracting the stones. It is for this reason that I prefer to know preoperatively whether or not stones are lodged in the common bile duct.

Technique

Two approaches are possible for laparoscopic choledochal exploration. The first approach is through a cystotomy in the cystic duct with subsequent dilation of the cystic duct to a point where a flexible choledochoscope can be advanced through the cystotomy into the common duct. Extraction of the stone is then possible using a basket technique through the choledochoscope.

If it is not possible to perform the choledochoscopy through the cystic duct, choledochoscopy is possible through a vertical incision in the common bile duct following placement of stay sutures on either side planned of the choledochotomy. Again, the choledochoscope is introduced into the common bile duct and the stones

are removed. With this approach it is suggested that a T tube be positioned through the choledochotomy and the choledochotomy approximated around the T tube. The T tube can then be exteriorized through the right lateral abdominal port incision. It is also recommended that a closed suction drain is placed in the area of the common bile duct and it can also be exteriorized through the right lower 5 mm incision. (Fig. 11.9) A cholangiogram is performed 4 to 6 weeks postoperatively. If there is no evidence of leak around the T tube or residual common bile duct stones, the T tube is removed.

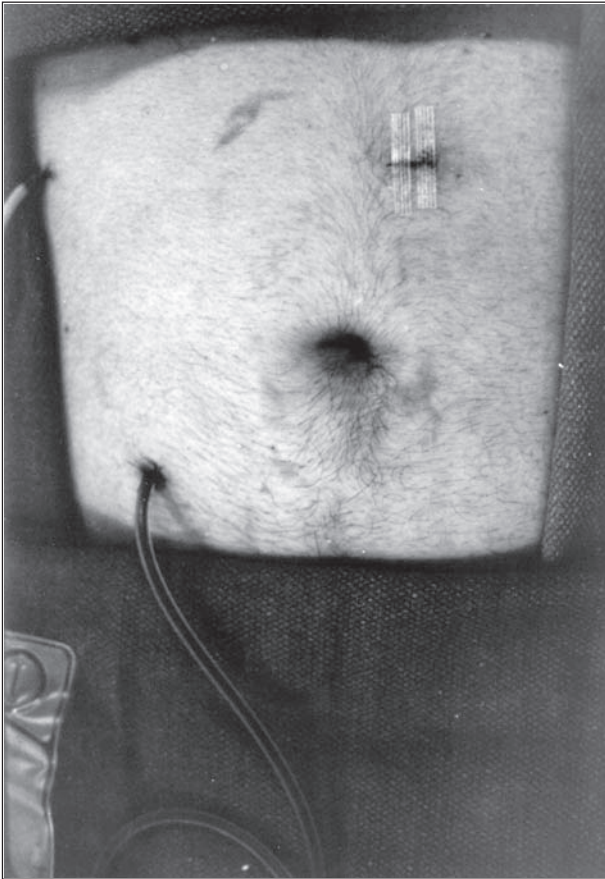


Figure 11.9. In this teenager who underwent laparoscopic choledochoscopy and extraction of a common duct stone, the T tube is exteriorized through the right lateral 5 mm incision. A closed suction drain is delivered through the right inferior 5 mm port site. The umbilical incision has been closed.

As more and more pediatric surgeons are gaining experience with complex laparoscopic procedures, laparoscopic choledochotomy and choledochal exploration will become more common and obviate the need for open exploration.

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Pediatric Laparoscopic Gastrostomy

Elizabeth P. Owings and Keith E. Georgeson

Introduction

Gastrostomy is commonly employed for children who have swallowing difficulties or failure to thrive. Failure to thrive occurs in children with high metabolic requirements associated with chronic pulmonary or cardiac disease and children with profound neurological impairment. Other indications for gastrostomy include children with primary aspiration or difficult swallowing due to neurological or esophageal disorders. Any candidate for a gastrostomy should be evaluated for the presence of gastroesophageal reflux. A child needing a gastrostomy with clinically symptomatic gastroesophageal reflux should have a combined laparoscopic fundoplication and gastrostomy. If a fundoplication is not indicated, a laparoscopic gastrostomy can be placed in the lesser curvature which may help deter the development of gastroesophageal reflux after gastrostomy formation. Contraindications to laparoscopic gastrostomy include a planned laparotomy for another procedure, and excessive peritoneal adhesions which would preclude safe placement of the instruments.

Instrumentation

A single 3 mm or 5 mm trocar is used in the umbilicus. In most instances, a 3 mm scope allows adequate visualization for the procedure. The instruments needed include:

- Scope 0 degree, 3 mm
- Trocar, 3.5 mm, x2
- Grasper, 3 mm
- U-stitch
- Needle with guidewire
- Graduated dilators, x4 (Cook dilator set # C-JCDS-100-CHB PO Box 489, Bloomington, IN 47402)
- Catheter or balloon button
- Bolsters
- Needle holder (open), x2

Anesthesia

General endotracheal anesthesia is used for the procedure. The installation of bupivacaine hydrochloride 0.25 with epinephrine or large volumes of dilute xylocaine with epinephrine into the trocar sites helps with postoperative pain management.

Patient Positioning

Patients under the age of 5 years can usually be positioned at the end of the table with the legs folded. Older children can be placed in a similar position with the legs held in stirrups. The patient should be secured to the operating table with tape. The operating surgeon and his assistants stand at the foot of the table. The monitor is usually positioned just to the left of the patient's head.

Operative Technique

A nasogastric tube should be passed into the stomach before the procedure. The anesthetist should be prepared with a 60 cc catheter tipped syringe and a clamp to allow for sequential insufflation of the stomach through the nasogastric tube.

After the installation of the pneumoperitoneum to a pressure of 10 cm H₂O and placement of the umbilical trocar, a site is selected for the gastrostomy. The umbilical trocar may be stabilized as described in the chapter on gastroesophageal reflux disease. The gastrostomy site is usually located to the left of the midline and well below the left costal margin. A stab wound is made at the selected site with a number 11 blade pointed in a vertical axis and passed into the peritoneal cavity under laparoscopic surveillance. Care should be taken to keep the site away from the epigastric vessels to avoid bleeding. A 3 mm grasping clamp is passed directly through the stab wound into the peritoneal cavity. The anterior wall of the stomach is grasped at an appropriate site. For gastrostomy without fundoplication, the anterior wall of the stomach should be grasped just to the left of the lesser curvature. A second 3 mm trocar and grasper in the right upper quadrant may occasionally be necessary to retract the liver so that the anterior wall of the stomach can be better visualized. For gastrostomy performed with fundoplication, the gastrostomy may be sited closer to the greater curvature.

Care should be taken to avoid a gastrostomy that is placed close to the pylorus. The stomach is pulled up adjacent to the anterior abdominal wall. The anesthetist is asked to insufflate the stomach with air using the 60 cc catheter tipped syringe attached to the nasogastric tube. Two U-sutures are passed through the abdominal wall using a large round needle and a monofilament suture. (Fig.12.1) The U-suture should incorporate 1 cm of gastric wall. The suture should be placed through the abdominal wall and stomach parallel to the axis of the telescope. (Fig.12.2)

The U-sutures are then secured with a clamp outside the abdominal wall and the 3 mm grasping clamp is removed. The two U-sutures are used to draw the stomach against the abdominal wall. The anesthetist should insufflate the stomach with additional air to induce adequate distention of the stomach at this point. A Seldinger needle is introduced through the abdominal wall through the stab wound and through the gastric wall between the U-stitches. Care should be taken not to introduce the needle too far so that it traverses both the anterior and posterior walls of the stomach. (Fig.12.3) A guide wire is introduced into the stomach through the needle and the needle is withdrawn. The stomach should be allowed to fall away from the abdominal wall at this point to make sure the guide wire is in satisfactory position between the sutures. Graduated dilators are then passed over the guide wire using the U-sutures for countertraction of the anterior wall of the stomach until the tract is dilated sufficiently to accept a balloon tube or button. The tract should be dilated four French sizes larger than the planned gastrostomy device. A balloon-tipped button

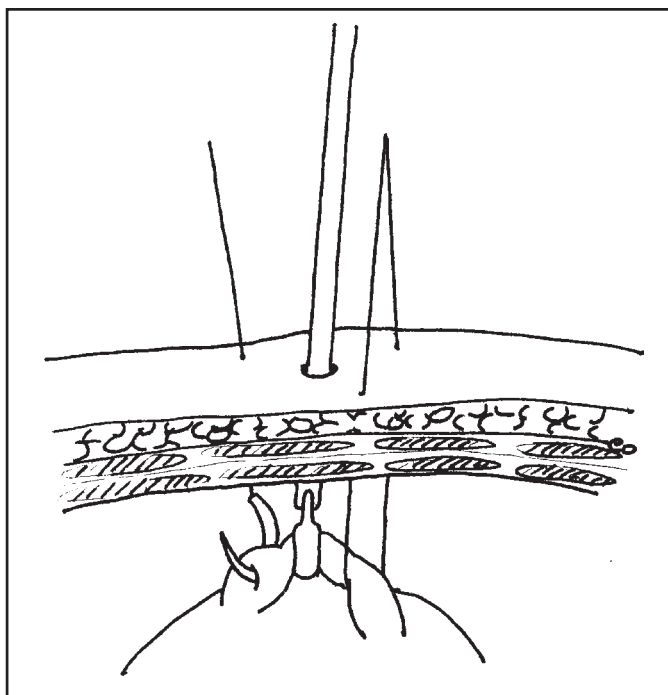


Figure 12.1. The stomach is grasped through a small incision at the proposed gastrostomy site. Two U stitches are placed through and through the skin and anterior gastric wall.

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or balloon tube is advanced over the guide wire and into the stomach. The appropriate stem length for a button should be roughly pre-measured with a dilator. Once the button or tube is seated in place, the U-sutures are tied over the wings of the button or over a bolster. (Fig. 12.4)

The U-sutures should be tied snugly. Care should be taken not to make them too tight. The umbilical trocar is removed and the trocar site closed. The U-sutures may be removed on the second postoperative day. Feeding can be commenced within 6-12 hours after the gastrostomy placement.

Feedings are delivered by bolus, continuous drip, or a combination of the two. The author prefers laparoscopic gastrostomy over percutaneous endoscopic gastrostomy and jejunostomy because of its increased versatility and safety.

Results

We have performed U-stitch gastrostomy in over 300 patients. Complications have been infrequent. Postoperative peri-gastrostomy leakage has occurred in a few patients and is usually prevented by using a small diameter tube (8-10 F) in infants weighing less than 6 kg with a very thin abdominal wall.

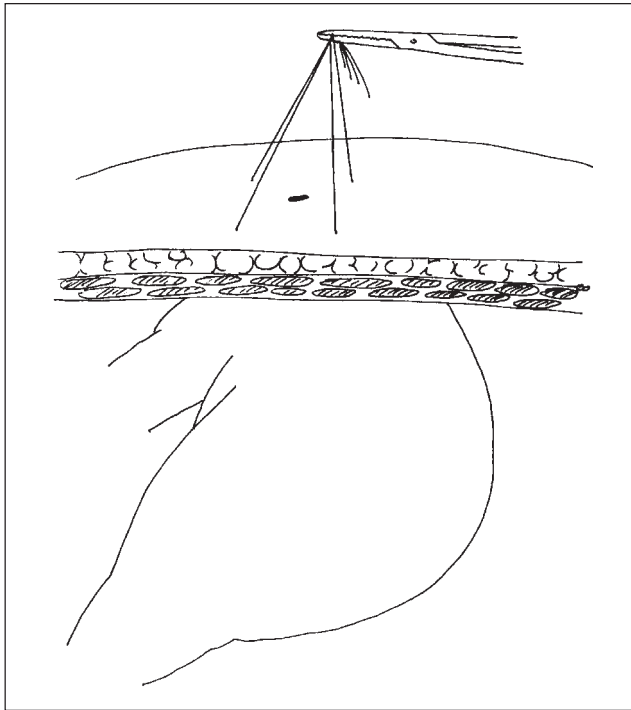


Figure 12.2. Traction on the U stitches brings the stomach up to the abdominal wall.

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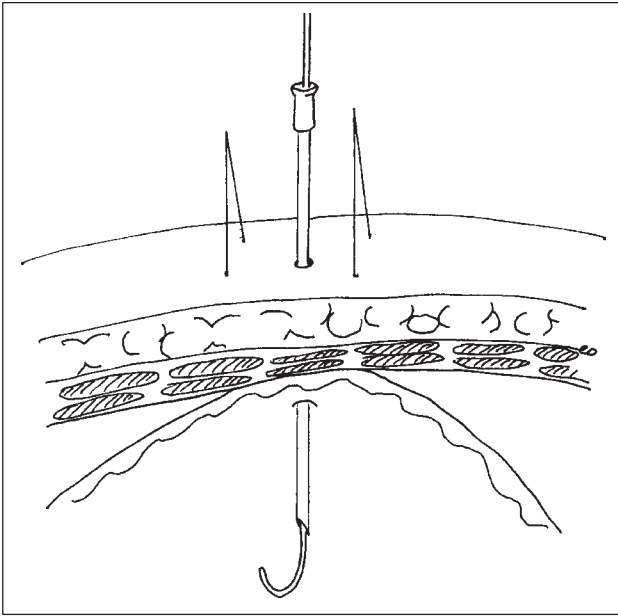


Figure 12.3. A needle is passed into the stomach between the sutures. A wire is threaded through the needle, then the tract is dilated.

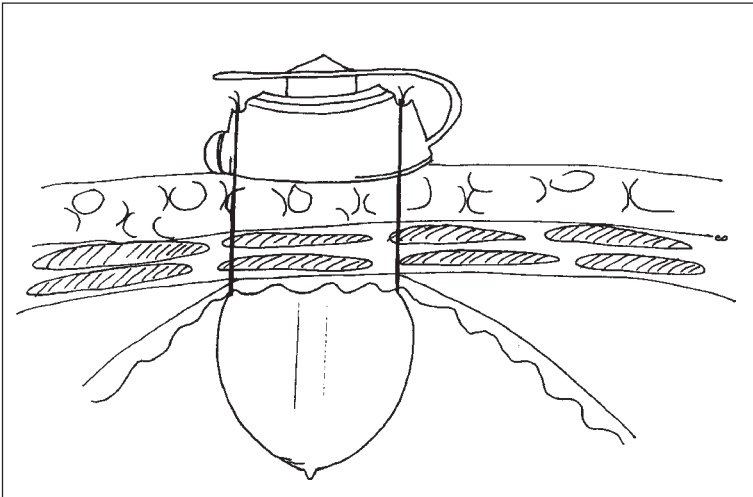


Figure 12.4. The gastrostomy device is inserted, and the U stitches are tied over the wings of the button.

Pediatric Laparoscopic Fundoplication

Elizabeth P. Owings and Keith E. Georgeson

Introduction

Gastroesophageal reflux is virtually ubiquitous in neonates, but operative intervention is infrequently required in this age group. Even symptomatic reflux in an infant will often spontaneously improve. Fundoplication is indicated when medical management fails to prevent the symptoms or complications of reflux, or if the symptoms are life threatening. Additionally, children over 1 year of age with medically controlled symptomatic reflux should be offered fundoplication in preference of lifelong medical management. Complications of gastroesophageal reflux include failure to thrive, reactive airways disease exacerbation, esophagitis with or without bleeding or stricture, Barrett's esophagus, apnea, recurrent subglottic stenosis and pulmonary aspiration. Infants with primary aspiration may have a fundoplication combined with a feeding gastrostomy. Laparoscopic fundoplication offers a reduction of the postoperative pain and morbidity associated with open fundoplication. The outcomes after laparoscopic fundoplication have been equivalent to open fundoplication and are associated with faster recovery. The senior author prefers complete fundoplication due to the lower incidence of recurrence as well as a diminished incidence of dysphagia in his patients. Partial wrap fundoplication is associated with higher recurrence rates, with no decrease in morbidity. Contraindications to laparoscopic fundoplication include the presence of excessive peritoneal adhesions which would preclude the safe introduction of trocars, and any planned open abdominal procedure. Relative contraindications include extreme hepatosplenomegaly which would make appropriate trocar placement difficult or very small patient size (less than 1500 g). However, if appropriate equipment is available and the operating surgeon is comfortable with the procedure, laparoscopic fundoplication has been performed safely even in infants weighing less than 2 kg.

Instrumentation

Infants

3.3 mm x 3 trocars (LUQ for gastrostomy)

4 mm x 1 trocar for scope

5 mm x 1 in umbilicus

Small Children

3.3 mm x 2 trocars

4 mm x 2 trocars (use one for liver retraction)

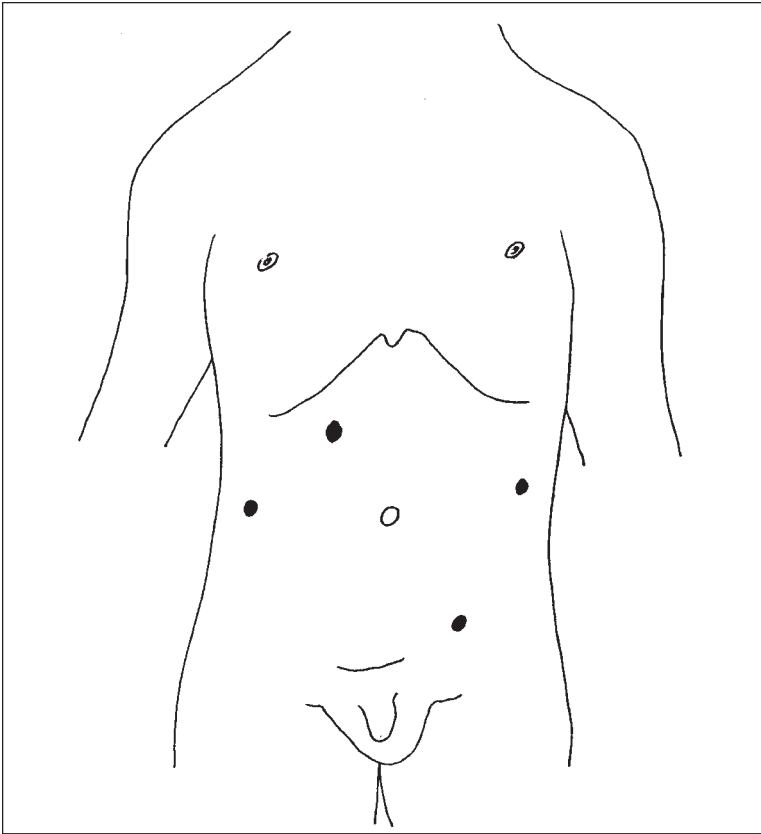


Figure 13.1. Port placement. The camera is placed in the umbilical port. The open circles denote the placement of trocars in small infants.

Large Children

5 mm trocars x 5

All Patients

Innerdyne trocar (Tyco)

30 degree scope (3, 4, or 5 mm depending on size)

Red rubber catheter for stabilization

Metzenbaum scissors (3 or 5 mm depending on size of child)

Grasping forceps (3 or 5 mm)

Babcock 5 mm

Hook 3-5 mm electrocautery

Needle driver

Ski needles (Ethicon)

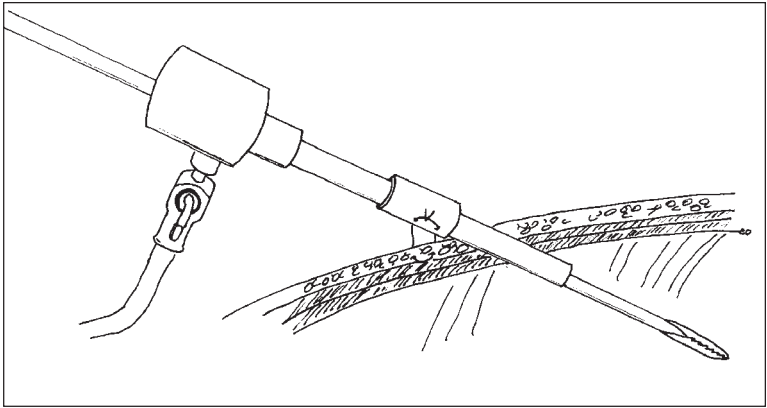


Figure 13.2. Optional port stabilization. The working ports are stabilized by passing them through a section of red Robinson catheter. This keeps the port from slipping into the peritoneal cavity, and a skin suture through the sleeve keeps the port from slipping out and holds it in a functional position.

- 2-0 or 3-0 silk on curved or ski needle
- Snake retractor (Snowden-Pincer)
- 3.3 to 5 needle holder (depending on size)
- Unipolar cautery
- Bougies
- Red Robinson catheter (optional)

Anesthesia

General endotracheal anesthesia is used for the procedure. Bupivacaine hydrochloride 0.25% with epinephrine can be injected into the trocar sites to lessen postoperative pain. Toradol IV may be given every 6 hours for up to 48 hours to decrease postoperative discomfort.

Patient Positioning

The patient is positioned at the end of the table with his legs taped in a cross-legged position. Pressure points are avoided as they can lead to peripheral neuropathy. Older children and adolescents are placed in stirrups. All patients are positioned in steep reversed Trendelenburg's position with the operating surgeon standing at the foot of the table between the legs. A large esophageal bougie is placed, with the diameter of the bougie appropriate to the size of the patient.

Operative Technique

After pneumoperitoneum is achieved, five trocars are placed in the upper abdomen. (Fig. 13.1) Trocar sizes are from 3 to 5 mm in diameter. Longer trocars are usually unnecessary except in obese adolescents.

We have found that stabilizing the working ports is helpful, particularly in smaller infants where internal or external migration of the port prevents optimal use of the

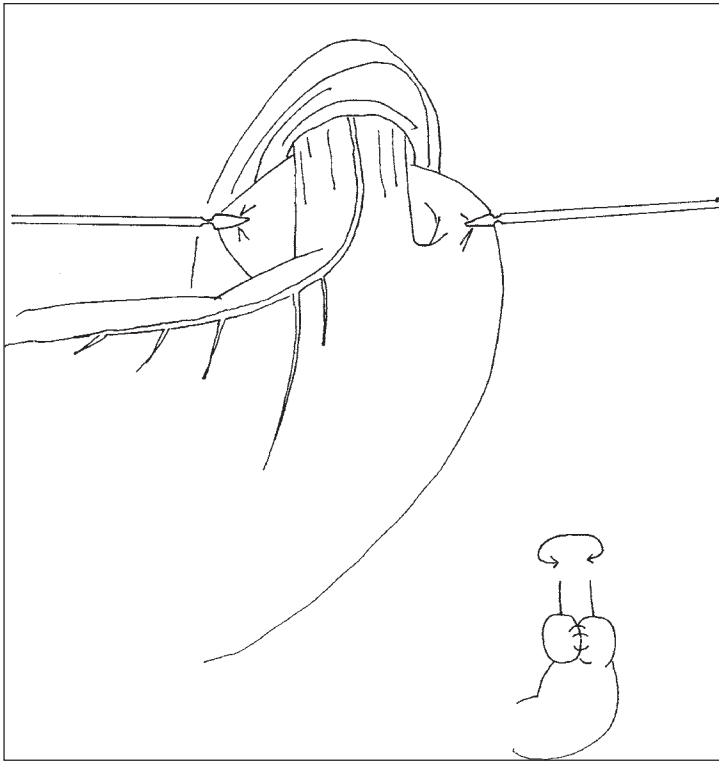


Figure 13.3A. Correct alignment of fundus. Gently pulling on each edge of the fundus in a “shoe shine” maneuver assures that the wrap will form a ring.

laparoscopic instruments. A 1 cm “sleeve” of red Robinson catheter, which will fit snugly around the port, is placed on the port before insertion into the abdominal cavity. The port is placed as usual. The rubber sleeve is sutured to the skin, which leaves the port at a 30° angle to the skin. This trocar practice facilitates introduction of instruments. The port can be adjusted within the sleeve, allowing for a deeper or more superficial position of the port, while accidental slippage is virtually eliminated (Fig. 13.2).

A retractor is placed through the right-lateral trocar site for retraction of the liver. The left lower quadrant grasper is manipulated by the first assistant, who also operates the telescope. Two operating ports are sited on either side of the optical port. The working ports are placed several centimeters lower in small infants and children to facilitate dissection and sewing.

The dissection of the hiatus is begun by dividing the gastrohepatic ligament. Cauterization of the liver is avoided because liver eschars can become the site of adhesions making reoperation of the hiatus more difficult. The left lobe of the liver

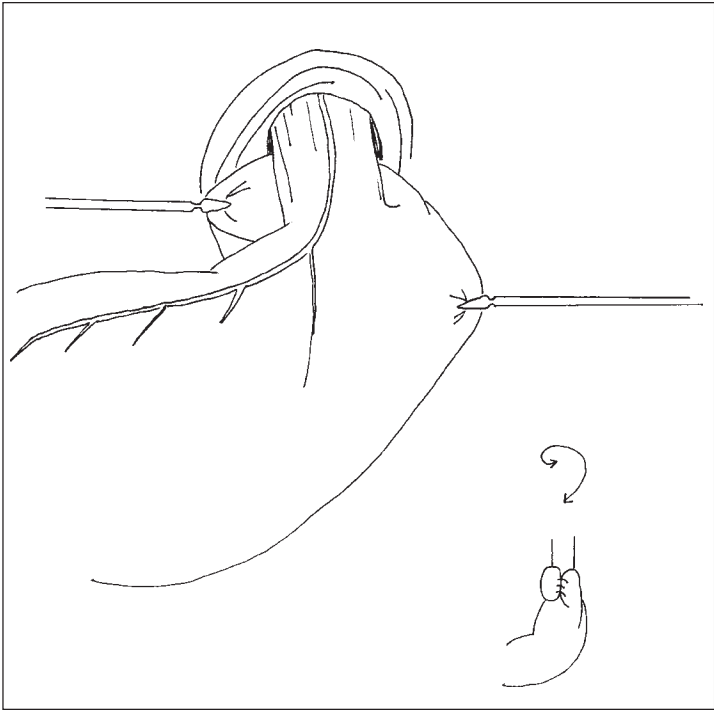


Figure 13.3B. Incorrect alignment of fundus. Gentle traction on each edge of the proposed fundoplication site moves the tissue in a spiral. The wrap will not be as effective.

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is retracted away from the esophageal hiatus with a multiarticulated or other appropriate retractor.

The phrenoesophageal ligament is incised over the esophagus and down toward the short gastric vessels. The short gastric vessels are divided by using an L-hook cautery. The fundus is separated from the diaphragm, and the crura are dissected on either side of the esophagus using sharp and blunt dissection. A window is developed behind the esophagus, leaving the posterior vagus with the esophagus. The window is enlarged to allow the fundus to be pulled through without encroachment. The crura are approximated posteriorly with one or two figure-of-eight non-absorbable sutures. The fundus is pulled through the retroesophageal window. If both edges of the proposed wrap can be pulled back and forth gently in a “shoe shine” maneuver, a functional complete wrap will be obtained. (Fig. 13.3A) If the wrap is constructed too far inferior on the left side of the stomach, the wrap forms a spiral instead of a ring and will not prevent reflux as effectively. (Fig. 13.3B) The sutures are placed through one edge, then tacked superficially to the esophagus avoiding the vagus, then through the other fundal edge and tied. (Fig. 13.4) For a Nissen fundoplication, a 2 cm wrap is constructed with interrupted sutures by attaching

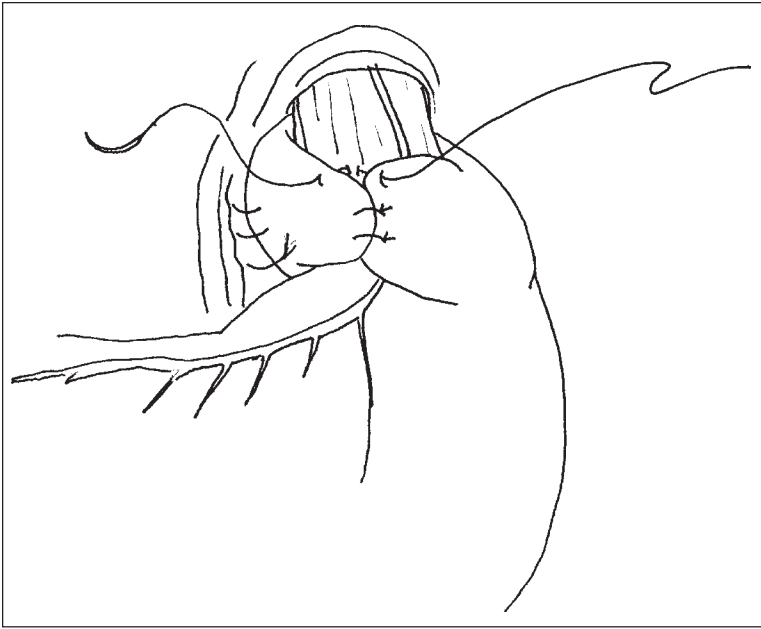


Figure 13.4. Nissen fundoplication. The fundus is wrapped completely around the esophagus and secured with interrupted sutures for 2 cm. The suture line passes through one leaf of the fundus, the esophagus, and the other leaf of the fundus before being tied.

the fundus to itself anteriorly at the 10 o'clock esophageal position. The fundoplication is then secured to the undersurface of the diaphragm with 2 or 3 non-absorbable sutures to prevent migration of the wrap into the chest.

A partial wrap is constructed by attaching the right side of the fundus to the right crus with a running 2-0 or 3-0 nonabsorbable suture. The fundus is secured to the right side of the esophagus with a running 2-0 or 3-0 nonabsorbable suture. The fundus to the left of the esophagus is secured to the left crus with interrupted non-absorbable sutures. A running suture is then used to approximate the left side of the fundus to the left side of the esophagus. This results in a 270°-300° wrap around the posterior portion of the distal esophagus. (Fig. 13.5)

Results

We recently reviewed our experience with 268 laparoscopic fundoplications over a three-year period. The overall recurrence rate was 8%, with 12% in the Toupet fundoplication group and 5.5% in the Nissen fundoplication group. Among neurologically normal patients, the Nissen fundoplication required reoperation in less than 2% of patients. Overall, we found the Nissen fundoplication to be a superior operation, with a lower incidence of recurrence, as well as a lower incidence of dysphagia and gas bloat symptoms in our patients.

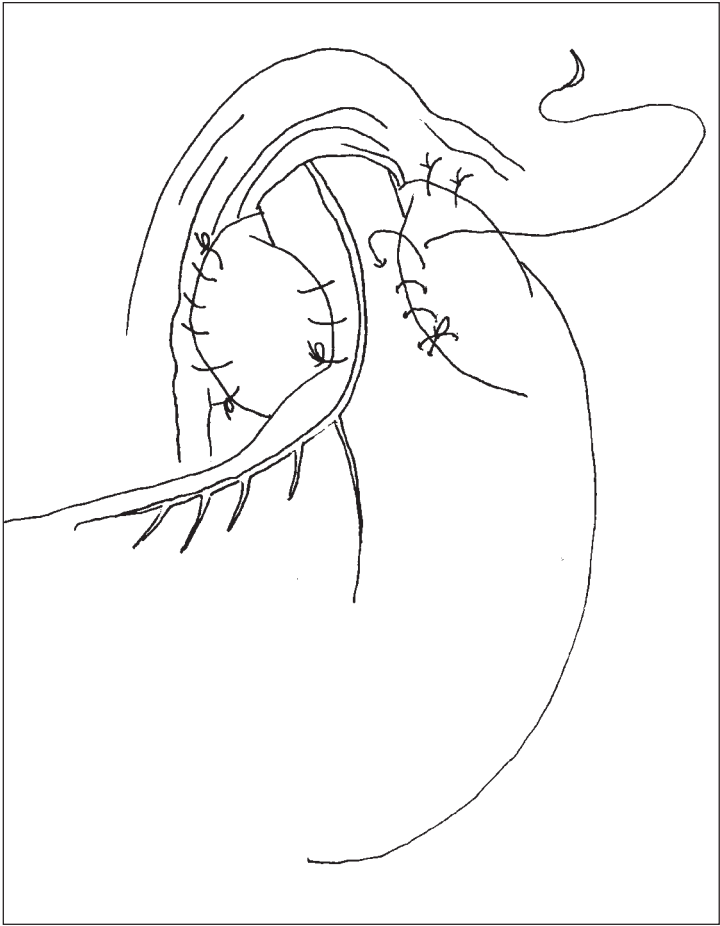


Figure 13.5. Toupet fundoplication. The fundoplication is a 270°-300° wrap secured to the esophagus with running sutures. The fundoplication is stabilized by suturing it to the diaphragm on both sides.

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Splenectomy

Frederick J. Rescorla

Splenectomy is frequently required in children with hematologic disorders such as hereditary spherocytosis, immune thrombocytopenic purpura (ITP) and sickle cell disease. The use of laparoscopic splenectomy was first reported in adults in 1991 and subsequently in children in 1993. The advantages cited in most series include less pain, absence of postoperative ileus, shorter hospital stay and improved cosmesis. The laparoscopic removal of large spleens can be difficult and operative times are longer and conversion to open rates higher than with removal of smaller spleens. Concerns have been raised about the efficacy of laparoscopic splenectomy in patients with ITP related to identification of accessory spleens and the possibility of splenosis if the splenic capsule is disrupted. Evaluation of cost comparison between open and laparoscopic splenectomy is difficult. The operative cost due to use of equipment and disposable devices is higher and this must be balanced against the shorter length of hospital stay.

Preoperative Preparation

The most common hematologic indication for splenectomy in children is hereditary spherocytosis. This autosomal dominant disorder generally results in a mild anemia and elevated reticulocyte count. Severe anemia can occur however in association with viral infections. This and other disorders with increased hemolysis can lead to the development of gallstones and these children should have a preoperative ultrasound and if stones are identified, a cholecystectomy. Another relatively common indication for splenectomy is ITP. Although most children with ITP respond to medical management or observation, some with persistent thrombocytopenia may require splenectomy. Although sickle cell anemia usually results in splenic infarction some children develop sequestration of platelets or red blood cells and require splenectomy. Other less common indications for splenectomy include beta thalassemia, Gaucher's disease and occasionally Hodgkin's disease. Due to the risk of postsplenectomy sepsis, all patients receive vaccinations for pneumococcal pneumonia, *Hemophilus influenzae* type B (if not administered with routine childhood vaccinations) and *Neisseria meningitidis*.

Technique

Several initial reports utilized techniques such as preoperative embolization and balloon occlusion of the splenic artery. The use of a hand-assisted technique in which the surgeons hand and arm are introduced through a Pfannenstiel incision has also been reported. These techniques are currently not required in children.

Operative Preparation and Position

After induction of general anesthesia the stomach is decompressed with an oral gastric tube and the bladder emptied with a Foley catheter. Lower extremity sequential compression devices are used if possible and if not the legs are wrapped with ace wraps. Most surgeons utilize the right lateral decubitus position in which the spleen "hangs" in the left upper quadrant (Fig. 14.1); however the supine position can also be utilized. At our institution the patient's left side is elevated 45° (Fig. 14.2) with the operating table in a level position. A small roll is placed under the right flank to flex the spine to the right. The operating table then can be tilted either direction to approach a level or a right lateral decubitus position.

Trocar Placement

The table is tilted to the patient's left for trocar placement and they are placed in the positions identified in Figure 14.1. This author utilizes a 15 mm umbilical trocar placed with an open technique. This allows placement of a 10 mm telescope, endo GIA stapler if needed and the 15 mm diameter specimen bag device (Endo Catch II, US Surgical Corporation, Norwalk, CT). Placement of a suture (2-0 silk) through the skin adjacent to the trocar can be useful if there is a small CO₂ leak and it is secured around the CO₂ port to prevent inadvertent trocar removal when withdrawing the telescope. Another option is to use a 10-12 mm trocar and then remove the trocar completely when placing the specimen bag device.

The other three trocars (5 mm) are placed under direct vision. Either B or C can be a 2 mm trocar however the other usually must be a 5 mm to allow the sturdier instrument to hold up the heavier spleens. If a cholecystectomy is indicated a fifth

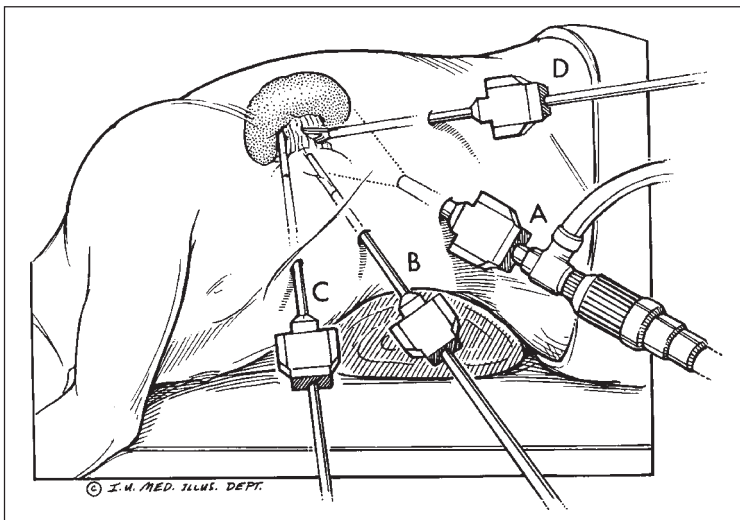


Figure 14.1. Trocar location for laparoscopic splenectomy. Port A, 15 mm for scope, disposable bag device, and stapling device. Ports B and C, 5 mm. Port D, 5 mm for ultrasonic scalpel, clip applicator, and scope.

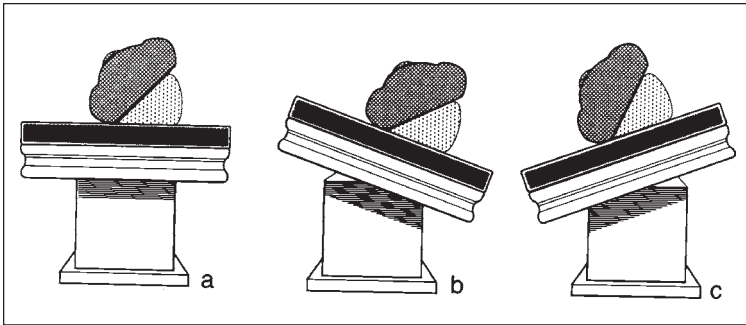


Figure 14.2. Patient position: view from foot of bed. a) Child on table with left side elevated 45 degrees. b) Table tilted maximally to the patient's left side for trocar placement. c) Table tilted maximally to the patient's right to achieve a right lateral decubitus position for laparoscopic splenectomy.

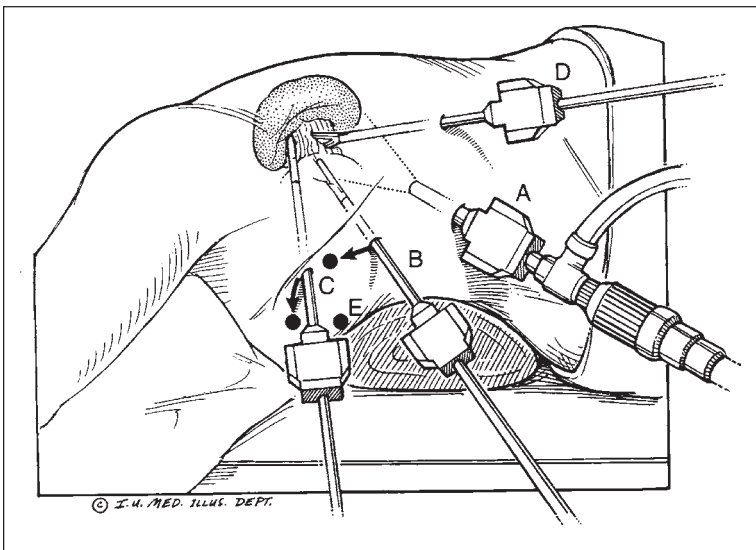


Figure 14.3. Trocar location of combination laparoscopic splenectomy and cholecystectomy. Ports B and C shift slightly for cholecystectomy and E is added as a fifth trocar. Port E is used only during the cholecystectomy.

trocars is added (Fig. 14.3) and trocar C is moved to a right subcostal position in the midclavicular line. This author prefers to perform the cholecystectomy prior to splenectomy.

Laparoscopic Splenectomy

After insertion of the trocars the table is tilted to the right to place the patient in the right lateral decubitus position. The surgeon and first assistant are positioned as noted in Figure 14.4. The first assistant usually controls two blunt graspers through trocar sites B and C (Fig. 14.1) and the surgeon controls the camera with the left hand and the harmonic scalpel with the right hand (port D).

The surgeon must be alert for the detection of accessory spleens. If present they can usually be detached with the use of the harmonic scalpel on the feeding vessel. Most accessory spleens will not fit through the 5 mm trocar and therefore a 5 mm telescope is placed through one of the other trocars and a grasper placed through the 15 mm umbilical trocar for specimen removal.

The omentum is pulled off the spleen to an inferior location. The lower splenic pole is elevated and the splenocolic attachments are divided with the harmonic scalpel. (Fig. 14.5) The gastrosplenic ligament is opened through a clear area (Fig. 14.6) and the short gastric vessels divided with the harmonic scalpel. Use of the harmonic scalpel is usually the most efficient method even though use of clips or cautery with scissors or hook could also be utilized. The lesser sac is carefully examined for accessory spleens. The most superiorly located short gastric vessels are often very short and the harmonic scalpel should be kept a few millimeters from the gastric wall to

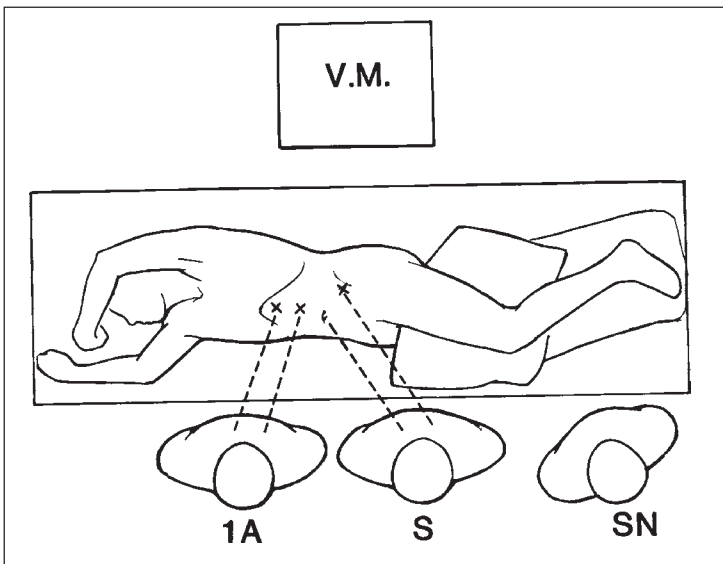


Figure 14.4. Location of personnel and equipment for laparoscopic splenectomy. VM, video monitor; S, surgeon; 1A, first assistant; SN, scrub nurse.

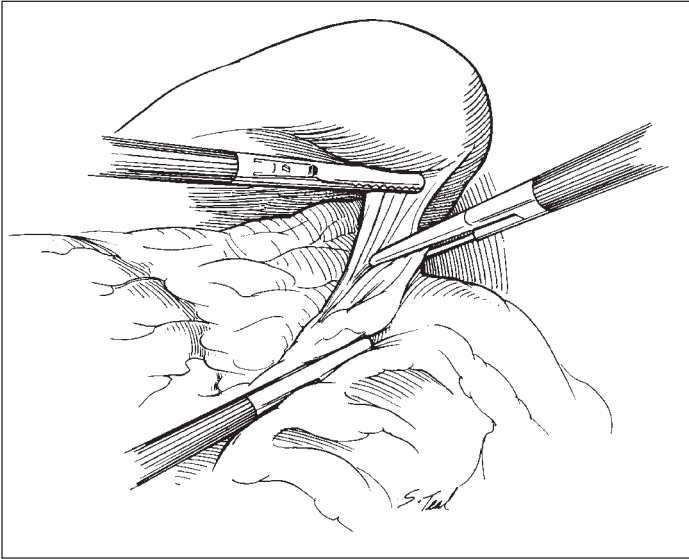


Figure 14.5. Harmonic scalpel dividing splenicocolic ligament as one blunt grasper elevates spleen and the other provides countertraction.

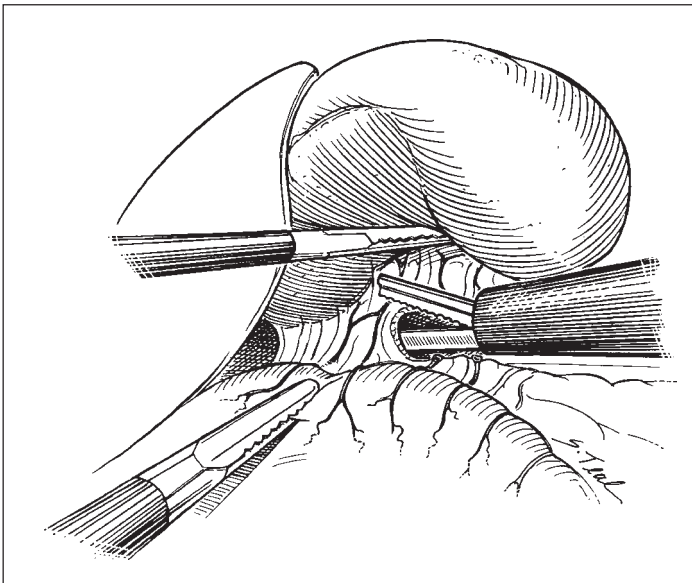


Figure 14.6. Use of the harmonic scalpel to divide the gastrosplenic ligament.

avoid thermal injury. After the short gastric vessels are divided it is often convenient to detach the attachments to the diaphragm.

The splenorenal can be divided as the next step. However once this is divided it is occasionally more difficult to work on the hilar vessels particularly if they are to be clipped and divided. The other option is to divide the hilar vessels next leaving division of the splenorenal ligament for later.

The hilar vessels are often amenable to individual division between clips. In this situation use of a dolphin nose forceps is often useful in the first assistant's right hand. Once the vessels are isolated a 5 mm clip-applying device (Endo Clip, US Surg Corp, Norwalk, CT) is passed through port D. Two clips are placed on the pancreatic site, one on the splenic side and the vessel divided with scissors. If the pancreas is intimately attached to the spleen the vessels must be handled in this fashion to avoid pancreatic injury. If however the pancreas is separated from the hilum by one centimeter or more, a stapling device can be utilized to divide the hilar vessels. Once the surgeon has decided to use the stapler it is often preferable to divide the splenorenal ligament so the spleen can be lifted and rotated as needed to ease application of the stapler. At this point a 5 mm telescope is placed through a separate trocar (usually left lower quadrant) and the stapling device (Endo GIA, 30-2.5; US Surgical Corporation, Norwalk, CT) placed through the umbilical trocar (Fig. 14.7). One and occasionally two applications of the device are utilized to divide the vessels.

After the spleen is completely detached the area is inspected for bleeding. The spleen is positioned as high in the left upper quadrant as possible. The 5 mm telescope is placed through trocar D. The specimen bag (Endo Catch II, US Surgical, Norwalk, CT) is in a 15 mm diameter device which is inserted into the abdominal cavity. If the umbilical trocar is too far into the abdomen it may not allow the bag to be completely opened and it may need to be pulled back particularly in a small child. The bag is opened by advancing the metal ring into the abdomen. The spleen is then dropped into the bag (Fig. 14.8). The folded bag usually unfolds under the weight of the spleen. Care must be taken as the bag may easily separate from the metal ring making it much more difficult to position the spleen in the bag. The bag is 23 cm (nine inches) deep and 13 cm (5 inches) in diameter allowing even larger spleens to fit within the bag. The drawstring is tightened to close the neck of the bag and the metal ring is removed. The neck of the bag is then pulled into the trocar and the trocar removed. The neck of the bag is opened and the surgeon's index finger is introduced through the bag in order to fracture the intraabdominal spleen into small fragments (Fig. 14.9). A ring forceps may be useful to remove pieces. However care must be taken to avoid puncturing the bag with other instruments. The spleen is removed in pieces and after completed the bag is removed.

The telescope is placed back in the abdomen and the left upper quadrant examined for bleeding. Local anesthetic is placed around all trocar sites. The umbilical site is closed with fascial sutures. In infants an attempt should be made to close at least the anterior fascial layers at the other sites as trocar site herniation has been noted at 5 mm sites in infants.

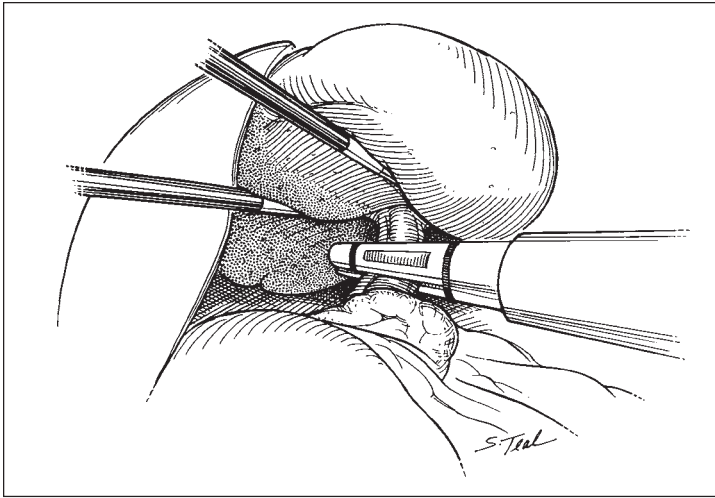


Figure 14.7. Use of an endoscopic stapling device to divide the splenic hilar vessels.

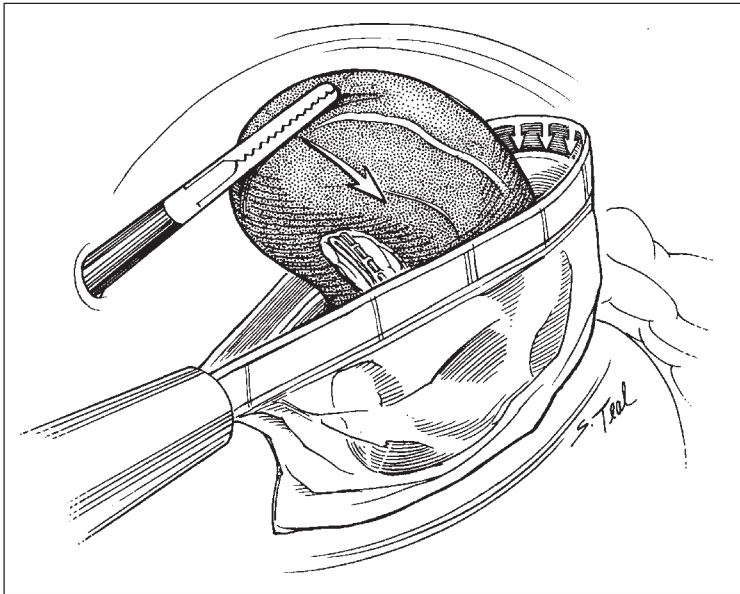


Figure 14.8. Placement of the spleen within the disposable bag.

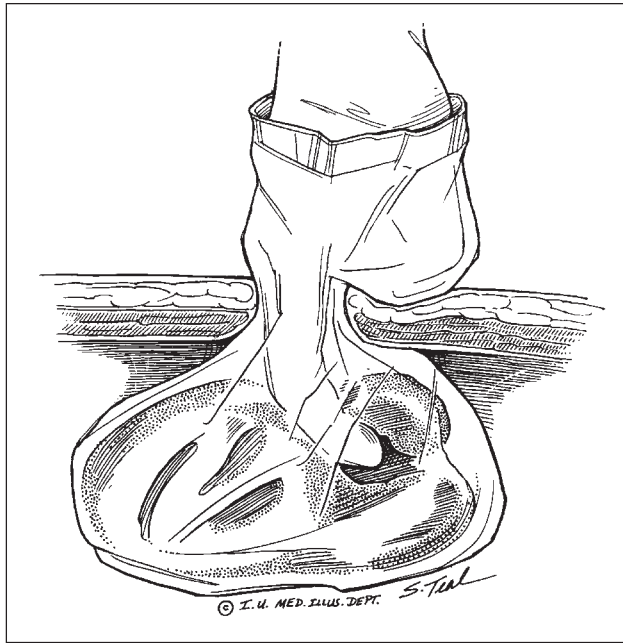


Figure 14.9. The neck of the bag is delivered through the umbilicus, and the surgeon's index finger is introduced into the bag to fracture the spleen into removable fragments.

Postoperative Management

Pain management is achieved with oral acetaminophen and codeine as well as intravenous ketorolac (0.5 mg/kg/dose every 6h for three to four doses) in children without thrombocytopenia. Liquids are offered to the child the afternoon of surgery and food either that evening or the following morning. Oral penicillin (≤ 5 years, 125 mg po bid, >5 yrs, 250 mg po bid) is started postoperatively for prophylaxis for post splenectomy sepsis. Most children can be released the day after surgery.

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Pediatric Laparoscopic Treatment of Hirschsprung's Disease

Elizabeth P. Owings and Keith E. Georgeson

Introduction

The recent trends in surgery for Hirschsprung's disease have been toward early repair and fewer surgical stages. The laparoscopic technique for colon pull-through continues this trend by combining a primary surgical repair with a laparoscopic technique which can be performed in newborn infants. Patients can be repaired within 1 to 2 days of diagnosis whether they be neonates or children. The colon lends itself to laparoscopic approaches due to its excellent collateral blood supply, ease of mobilization, the potential for removing specimens transanally and the use of transanal stapled anastomoses.

The diagnosis of Hirschsprung's disease must be confirmed with suction or operative mucosal biopsy prior to laparoscopic pull-through. The absence of ganglion cells and the presence of hypertrophic nerve trunks in combination with high levels of acetylcholinesterase extending up into the mucosal layer confirm the diagnosis. Barium enemas with follow-up anterior/posterior and lateral views after 24-hours are useful in planning the operation. A definitive transition zone can often be identified prior to the planned operation. Contraindications to one-stage laparoscopic pull-through include a diagnosis of total colon Hirschsprung's and an undetermined transition zone. Relative contraindications to laparoscopic pull-through include patients with a history of severe recurrent enterocolitis, patients who cannot be adequately decompressed preoperatively, and a long aganglionic segment, in which the transition zone is proximal to the splenic flexure of the colon.

Instrumentation

Scope 0 degree, 5 mm, 1x
Scope 30 degree, 5 mm, 1x
Trocar, 5 mm, 2x
Trocar, 3.5 mm, 2x
L-hook cautery, 3 mm, 1x
Grasper, 3 mm, 1x
Grasper with ratchet, 3 mm, 1x
Mosquito, 3 mm, 1x
Clip applier, 5 mm, 1x
Open procedure tray, 1x

Anesthesia

General endotracheal anesthesia is used. Bupivacaine hydrochloride 0.25% with epinephrine can be injected into the trocar sites to lessen postoperative pain.

Patient Positioning

Smaller patients are positioned transversely at the end of the operating table. Arm boards placed parallel to the operating table can be used to widen the supporting surfaces for longer infants. The surgeon and his assistants stand over the head of the patient. The torso of the patient is elevated with four or five folded sheets allowing the head to extend backward out of the operating surgeon's way. The camera driver stands to either side of the operating surgeon and the assistant stands at the end of the table at the patient's left side. The monitor is positioned at the foot of the patient. The operation is performed with the patient in a moderate Trendelenburg position to induce the small intestine to slide out of the pelvis. Larger patients are placed on the operating table in a supine orientation. The legs and feet are placed in stirrups with the buttocks elevated on towels out at the end of the operating table.

Operative sterile preparation is begun by cleansing all skin surfaces from the buttocks downward. The preparation is extended to the nipples anteriorly and carried well out laterally so that most of the patient's torso below the nipples is cleansed circumferentially.

Operative Technique

One-stage laparoscopic pull-through is begun with the intraperitoneal dissection. Three ports are usually used; a fourth suprapubic retractor is optional. (Fig. 15.1) A 5 mm trocar is placed in the right upper quadrant several centimeters to the right of the midline and approximately 2-3 cm below the liver edge. A 5 mm trocar is also used in the right anterior axillary line at the level of the umbilicus. A 3.5 or 5 mm trocar is placed in the left anterior axillary line above the level of the umbilicus. The fourth trocar (3.5 mm) is placed to the right or left of the midline suprapubically taking care to avoid injury to the bladder during insertion.

The peritoneal cavity is entered after a pneumoperitoneum is obtained. Once the peritoneal cavity is entered, the transition zone should be identified. Biopsy confirmation of the transition zone must be made prior to performing the irreversible step of endorectal dissection. Biopsies are taken using the endoscopic Metzzenbaum scissors to cut a small wedge of seromuscular tissue. The colon is grasped with fine-tipped forceps and scissors are used to create a tangential biopsy specimen. A single suture closes the biopsy site and clearly marks the biopsy location. The specimens are sent to the pathologist to aid in identification of the level of ganglionated bowel. The pelvic dissection should not be started until the operating surgeon is certain that the candidate is suitable for a one-stage procedure. If the operating surgeon is in doubt about the level of transition zone, it is much better to perform a leveling loop colostomy than to proceed with a primary pull-through.

The primary pull-through begins with development of a window through the rectosigmoid mesocolon behind the superior rectal vessels. A 3 mm grasping instrument is passed through the suprapubic trocar and the rectosigmoid colon is grasped. The colon is then pushed toward the anterior abdominal wall, displaying the rectosigmoid mesocolon. Using scissors or L-hook cautery, a window is developed in

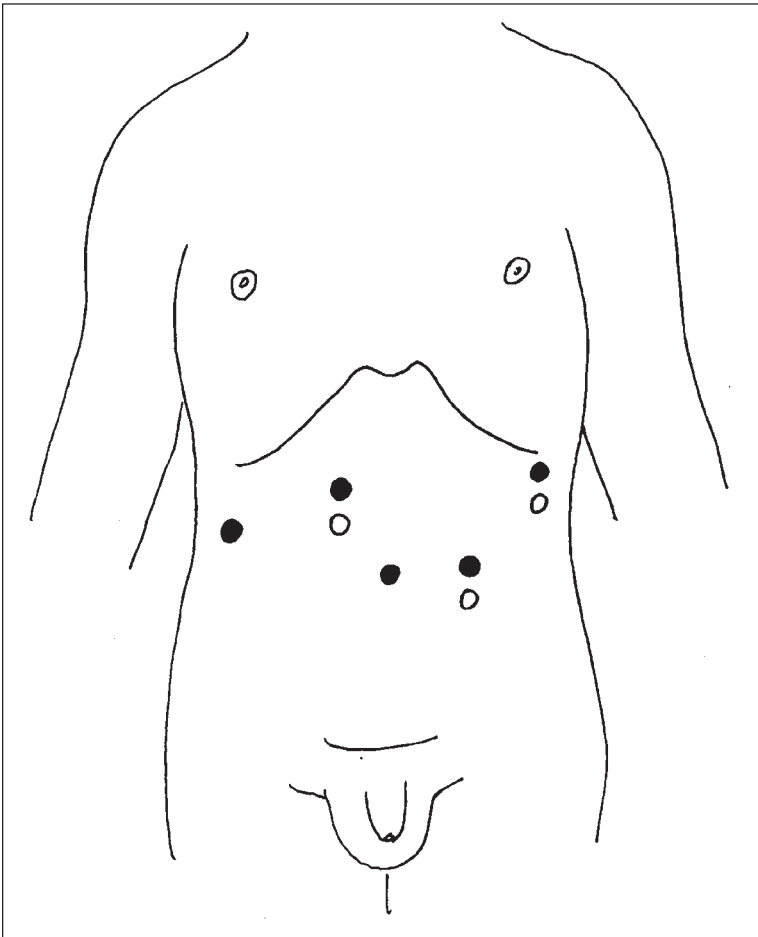


Figure 15.1. Port placement. The camera is placed in the highest right upper quadrant port. The open circles denote alternate port sites.

the rectosigmoid mesocolon behind the superior rectal artery and vein. The artery and vein are cauterized or clipped and divided. Dissection distally from this point is performed circumferentially close to the rectal wall. Dissection of the mesocolon proximal to this point is performed preserving the integrity of the marginal artery. In this way the colon pedicle retains adequate blood supply.

The pelvic dissection is started by circumferentially clearing the rectum of supporting structures and vessels. The L-hook cautery is very useful for this dissection although endoscopic bipolar Metzenbaum scissors or the ultrasonic scalpel can also be used. During the dissection of the rectum, both ureters should be visualized and

carefully preserved. The circumferential dissection is stopped just proximal to the prostate or cervix anteriorly. Posteriorly the dissection is continued down to the fourth or fifth sacral vertebra. The middle rectal vessels and supporting tissues are divided with electrocautery to join the anterior and posterior planes.

Once the laparoscopic pelvic dissection is completed, attention is turned to developing an adequate colon pedicle for the pull-through. For a transition zone in the distal sigmoid colon, the fusion fascia of the descending colon can be left intact. If the transition zone is in the mid or upper sigmoid colon or is in the descending colon, the fusion fascia attaching the colon to the lateral abdominal wall should be divided sharply using Metzenbaum scissors and a grasper. Once the fusion fascia has been divided, attention is turned to the mesocolon. An instrument is passed through the suprapubic trocar site to hold the colon toward the anterior abdominal wall, displaying the mesentery. Carefully advancing the dissection proximal to the marginal artery, radially oriented vessels are either cauterized with the L-hook cautery, coagulated with the ultrasonic scalpel, Ligasure, or clipped with a 5 mm clip. This dissection is continued proximally as far as is necessary to bring the ganglionated colon pedicle down for rectal anastomosis without tension. Once adequate mobilization of the colon and its mesentery is obtained, the pneumoperitoneum is evacuated and the transanal dissection is commenced.

The feet are elevated over the patient's torso exposing the anus. The operating surgeon and assistant move to the other side of the table for this portion of the operation. Six to eight traction sutures are placed through the perineal skin and through the mucocutaneous junction retracting the anorectum radially in all directions and exposing the rectal mucosa for dissection. Great care should be taken throughout the rectal dissection not to overstretch the anal sphincters, which could lead to fecal incontinence. A site is selected about 10 mm above the dentate line (Fig. 15.2). This site is marked using a needle-tipped electrocautery dotting the mucosa circumferentially around the rectum. The cautery is then used to cut through the mucosa but not through the internal sphincter. Fine 4-0 or 5-0 silk sutures are used to secure the cut proximal lip of the mucosa to provide traction for the mucosectomy. Care is taken to stay inside the white circular muscle fibers of the internal sphincter carefully dissecting away the mucosa. Larger blood vessels are cauterized prior to dividing them. Both blunt and sharp dissection is required for this separation to go smoothly. Adequate time should be taken to develop the plane. Once the submucosal plane is established, the dissection progresses more quickly. The mucosectomy is continued proximally until the rectal sleeve turns inside out and prolapses through the anus.

A second indication that the dissection is proximal enough is the absence of bleeding during the mucosectomy because the bowel has been previously separated from its blood supply by the laparoscopic dissection. When the rectal sleeve prolapses out through the anus easily, the muscular coat is divided posteriorly (Fig. 15.3). If the intraperitoneal plane is not readily encountered with the first posterior cut through smooth muscle, the mucosectomy is continued up another 2 cm and another attempt to enter the peritoneal cavity is made. Once the dissection plane from above is entered transanally, the muscular cuff is cut circumferentially to free the colon from the surrounding cuff. Redundant portions of the proximal muscular sleeve are also trimmed to leave a sleeve about 5-6 cm around the neorectal reservoir (Fig. 15.4).

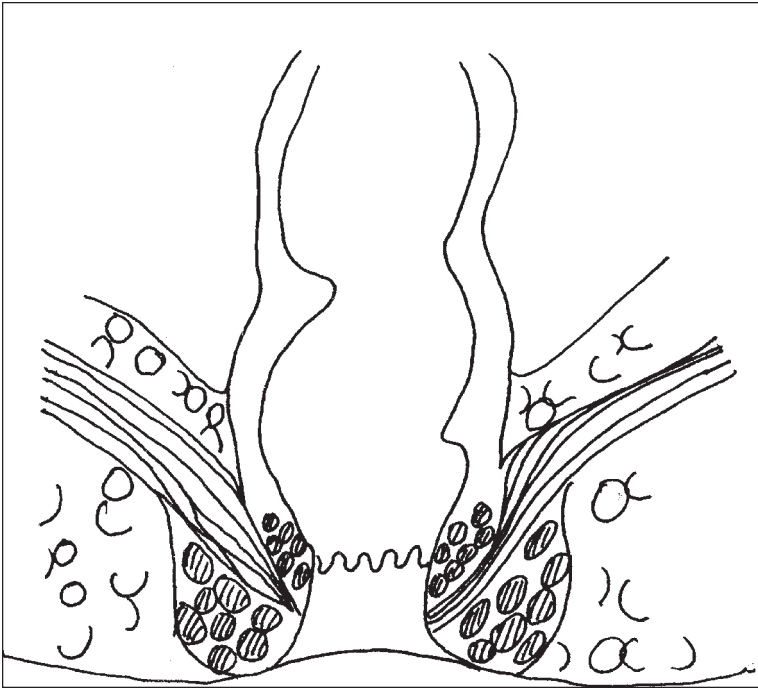
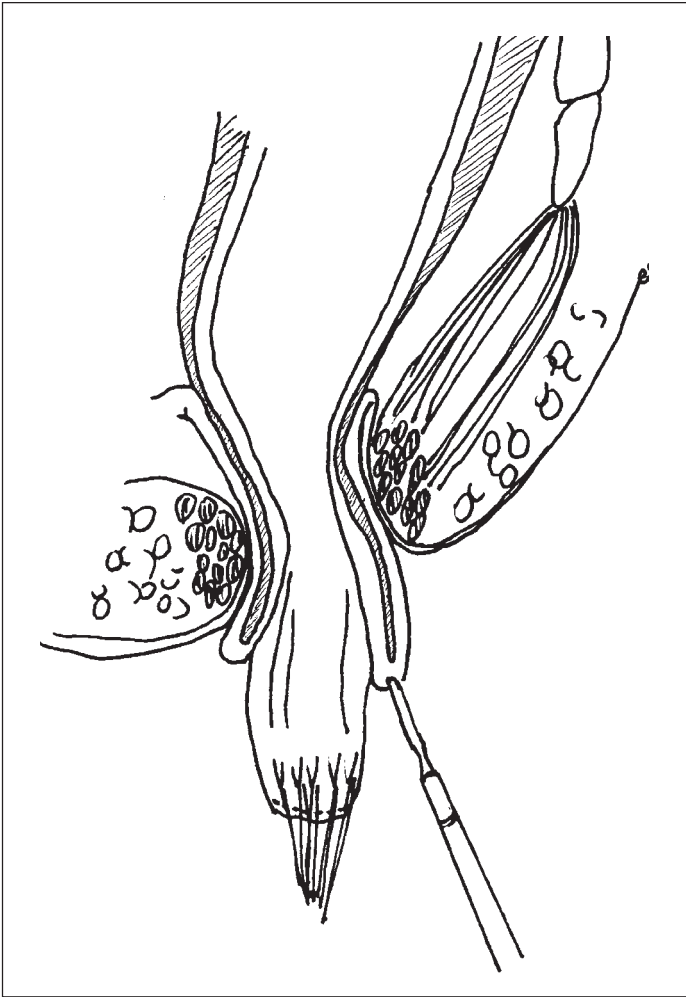


Figure 15.2. The transanal mucosal dissection begins by scoring the mucosa with electrocautery 10 mm above the dentate line.

The muscle sleeve is also divided posteriorly from the top of the muscle down to within 1 or 2 cm of the intended anastomosis. Dividing the muscle sleeve allows the neorectum to form a larger rectal reservoir. This division of the rectal cuff is optional and may be omitted by surgeons who prefer to leave an intact sleeve of rectal cuff.

The colon is next pulled down through the rectal sleeve until the transition zone is visualized. The author prefers to pull out an additional 5-10 cm of colon to ensure that the dilated dysmotile segment of the colon is resected. The colon is then transected about half way around its circumference beginning anteriorly. 4-0 absorbable sutures are placed anteriorly and laterally to hold the neorectum in position. The remainder of the colon is then amputated. The specimen is sent to the pathologist for frozen section analysis regarding the presence of ganglion cells in the proximal end of the specimen. The anastomosis is carefully made between the neorectum and the distal mucosal cuff (Fig. 15.5). Great care should be taken to avoid any potential anastomotic leaks. The absorbable sutures are left long until the anastomosis has been completed. The long sutures are used to help inspect each portion of the anastomosis to make certain there are no hidden defects in the anastomosis.

Once the anastomosis is completed, the sutures are cut to about 1 cm in length and the anal retraction sutures are removed. The anus then conforms to a normal



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Figure 15.3. The rectum telescopes out through the anus. The muscle layers are transected posteriorly to join the laparoscopic and transanal planes. The rectal muscle layers are divided circumferentially around the rectum.

position. The little finger, lubricated with saline, is used to evaluate the anastomosis and the neorectum.

The surgeons change their gloves and reinsert the pneumoperitoneum. The colon is observed to make certain it is not twisted as it proceeds into the pelvis. If there is a potential space behind the mesocolon for herniation of the small bowel, the space

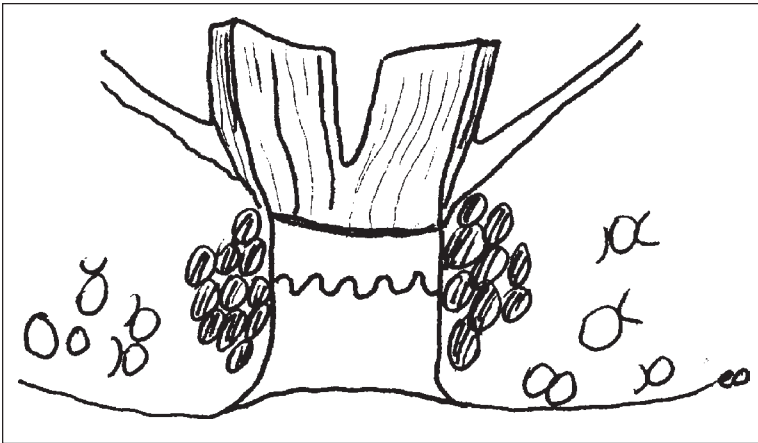


Figure 15.4. Excess muscular cuff is trimmed proximally leaving a cuff length of 5-6 cm. The cuff may be split posteriorly to allow for development of a rectal reservoir.

is closed using interrupted 3-0 silk sutures. The trocars are then removed and the fascia and the skin are closed in the usual fashion.

Infants and children who are not candidates for a one-stage pull-through should have an initial leveling colostomy. The transition zone is identified by taking multiple biopsies as previously described, and marked with a long suture. A 3 cm incision is made at the proposed colostomy site. The marking suture is grasped with a clamp and the colon is pulled up into the wound. A small opening is made through the adjacent mesocolon. The skin is pulled together through the mesenteric defect and approximated with one or two sutures between the proximal and distal portions of the loop. The colostomy is opened and matured with absorbable sutures. Prolapse can be prevented by attaching the colon to the anterior abdominal wall laparoscopically with several silk sutures. These sutures are placed both proximal and distal to the colostomy site through the seromuscular layer of the colon.

Patients who have had a previous loop colostomy are operated secondarily in a fashion similar to a one-stage pull-through operation. The procedure is begun by stapling both the proximal and distal ends of the ostomy closed. Six to eight sutures are used to approximate the two stapled ends to each other. The stoma is taken down and dropped into the peritoneal cavity. The wound is closed and the procedure is then performed as previously described for the primary pull-through.

Results

The author has recently evaluated the outcome of primary laparoscopic pull-through in 80 patients with Hirschsprung's disease performed at six pediatric surgery centers over the past five years. Most of the children were operated immediately after the diagnosis was made by suction rectal biopsy. The age at operation was 3 days to 96 months. The average length of operation was 2.7 hours. Only one patient required a perioperative blood transfusion. Most of the patients passed stool



Figure 15.5. The anastomosis is made with interrupted absorbable suture.

and flatus within 24 hours of surgery. The average time for discharge after surgery was 3.7 days. One of the patients required subsequent diversion for enterocolitis. All 80 patients are currently alive and well. Most of the children are too young to evaluate for fecal continence, but 18 of the older children are continent.

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Laparoscopic Management of Imperforate Anus

Elizabeth P. Owings and Keith E. Georgeson

Introduction

Infants with high imperforate anus have been classically treated in three stages with an initial diverting colostomy, subsequent posterior sagittal anorectoplasty, followed 3-6 months later by colostomy closure. Though this approach is cosmetically satisfactory, results regarding continence have been inconsistent. It is possible that dividing the sphincters during dissection and lining the anal canal with insensate mucosa negatively influence continence. Additionally, the lack of a normally functioning internal sphincter makes the attainment of complete fecal continence difficult to achieve. The deranged motility of the rectosigmoid colon in these patients adds complexity to successfully restoring fecal continence. Minimally invasive techniques have the advantage of decreasing the surgical stress to the delicate and incompletely formed continence mechanisms in children with high imperforate anus. The desire to preserve the sphincters, place sensate skin within the control of the sphincters, and shorten recovery has led to the development of this minimally invasive surgical technique. This technique can be performed in newborns as a single stage but the authors currently prefer to perform an initial diverting proximal sigmoid colostomy which is left in place for 2-3 months after the laparoscopic assisted pull-through to allow for adequate dilation of the newly constructed anus.

Instrumentation

Scope 0 degree, 5 mm, 1x

Scope 30 degree, 5 mm, 1x

Trocar, 5 mm, 2x

Trocar, 3.5 mm, 2x

L-hook cautery, 3 mm, 1x

Grasper, 3 mm, 1x

Grasper with ratchet, 3 mm, 1x

Mosquito, 3 mm, 1x

Clip applier, 5 mm, 1x

Open procedure tray, 1x

Expandable trocar, 5 mm (Innerdyne 1244 Reamwood Ave., Sunnyvale, CA 94089; catalogue S100705)

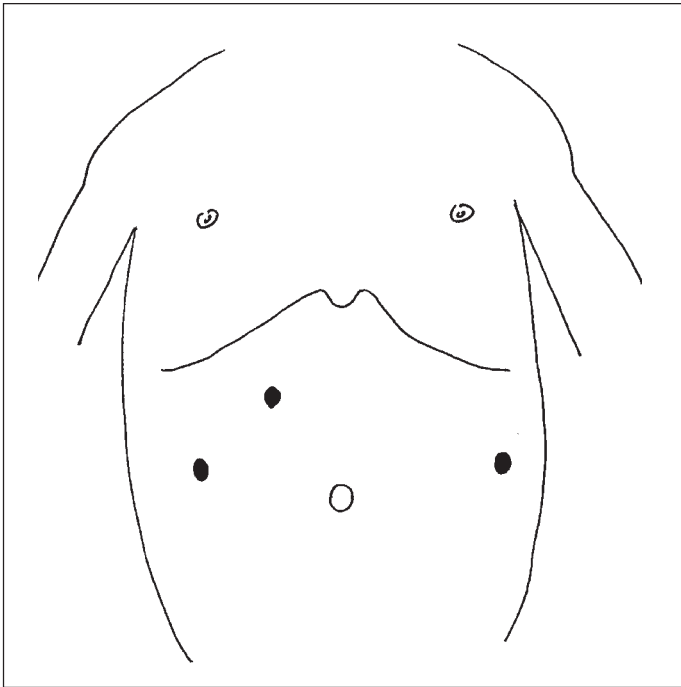


Figure 16.1. Port placement for laparoscopic. The open circle denotes the umbilicus. The camera is placed in the right upper quadrant port. The left lateral port is optional.

Anesthesia

General endotracheal anesthesia is used during the procedure. Bupivacaine hydrochloride 0.25% with epinephrine may be used in the trocar sites to lessen post-operative pain.

Patient Positioning

Smaller patients are positioned transversely at the end of the operating table. Arm boards placed parallel to the operating table can be used to widen the supporting surfaces for longer infants. The surgeon and his assistants stand over the head of the patient. The torso of the patient is elevated with four or five folded sheets allowing the head to extend backward out of the operating surgeon's way. The camera driver stands to either side of the operating surgeon and the assistant stands at the end of the table to the patient's left side. The monitor is positioned at the foot of the patient. A moderate Trendelenburg position is used to induce the small intestine to slide out of the pelvis. Larger patients are placed on the operating table in a supine orientation. The legs and feet are placed in stirrups with the buttocks elevated on towels out at the end of the operating table.

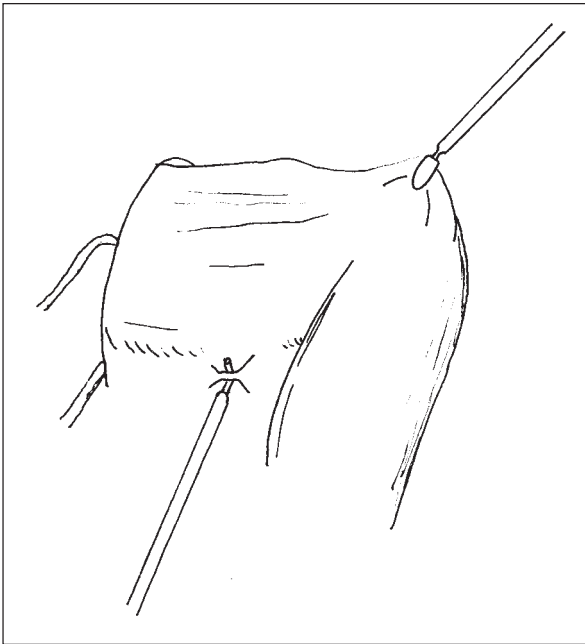


Figure 16.2. Beginning the dissection. The rectum is pulled laterally and a window is developed in the mesorectum with electrocautery.

Operative sterile preparation is begun by cleansing all skin surfaces from the buttocks downward. Anteriorly the preparation is extended to the nipples and carried well out laterally so that most of the patient's torso below the nipples is cleansed circumferentially.

Operative Technique

Preoperative preparation includes a standard bowel prep with distal colon irrigation if the patient already has a colostomy, and antibiotics. The bladder is catheterized to serve as a landmark during dissection and to minimize urethral narrowing when the fistula is clipped. Cystoscopic guidance will be necessary for catheter placement in patients with an accented angulation at the site of the rectourethral fistula. Exposure may be optimized by retracting the bladder with a large U-stitch through the skin. The abdomen is insufflated with CO₂ to a pressure of 10-12 cm H₂O. Three ports are usually sufficient for this operation. The camera is placed in the right upper quadrant just below the liver. One instrument port is placed in the umbilicus and another in the right anterior axillary line at the level of the umbilicus. (Fig. 16.1) A small window is first developed in the mesorectum at the level of the peritoneal reflection with an electrocautery. (Fig. 16.2) The rectum is mobilized beginning posteriorly and proceeding laterally and anteriorly in a circumferential fashion. This dissection should be performed with bipolar scissors to minimize tissue

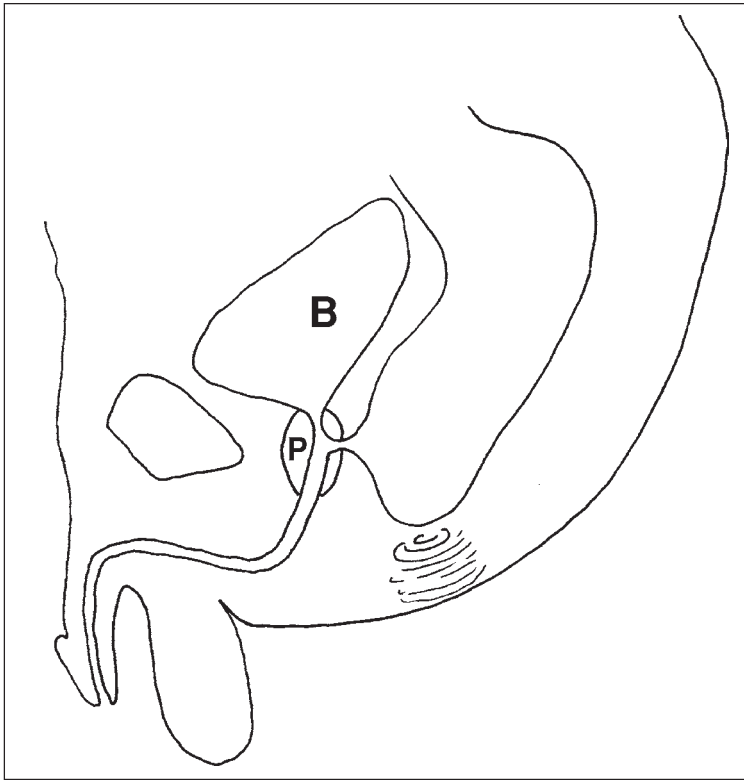


Figure 16.3A. Anatomy. The fistula enters the prostatic urethra. The sphincter bundle lies inferior to the rectum. P-prostate B-bladder.

destruction, especially anteriorly. The dissection should follow close to the muscle wall of the rectum. As the fistula is visualized, it is dissected free, and clipped or sealed with the Ligasure. The rectum is divided between the clips or the sealed portion (Fig. 16.3).

The external portion of the operation begins with the identification of the external sphincter muscles using a neural stimulator. The outer margin of the sphincters is marked on the skin with four quadrant sutures. (Fig. 16.4) The neoanus will be located at the center of the sphincter bundle where the neural stimulator causes a vertical dimple. The skin over the sphincters is incised in the midline for 6 to 8 mm. The central sphincter plane is identified with assistance of a backlighting transillumination by the laparoscopic camera. It is carefully dissected transanally by gently spreading open the plane through the sphincters for 1.5 to 2 cm. At the most cephalad point, the levator bundle is encountered and no plane will be identified. An Innerdyne Step trocar is used at this point to create the tract anterior to the levators which can be visualized with the laparoscope. This tract is then radially dilated up to 10 mm. The rectum is grasped and then brought out behind the trocar to the

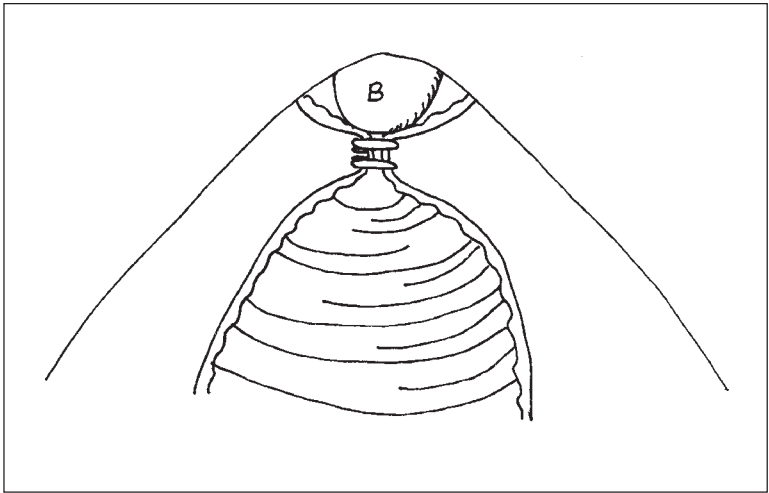


Figure 16.3B. Clips are applied to the fistula. B-Foley catheter balloon.

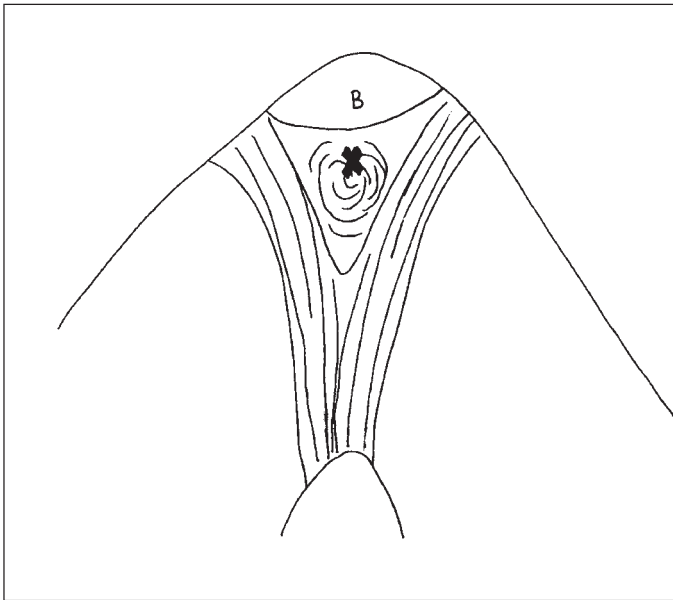


Figure 16.3C. Laparoscopic view after transection of fistula. The sphincter bundle can be discerned anterior to the pubococcygeus. The X demarcates where the trocar enters the peroneal cavity. B-bladder.

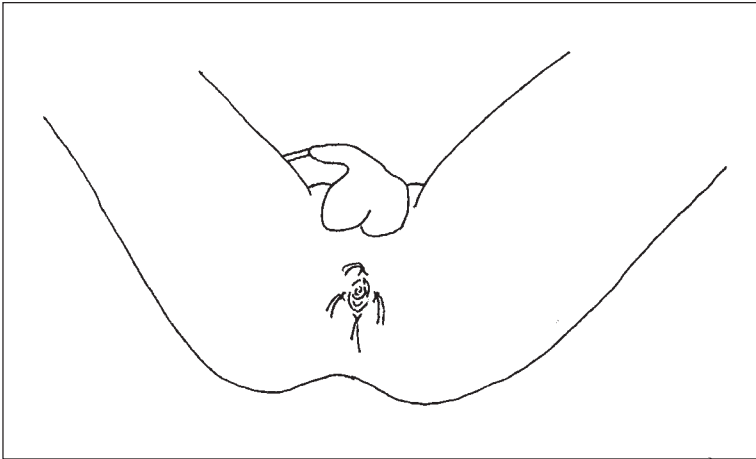


Figure 16.4. A neural stimulator identifies the sphincter bundle. The outer margin of the sphincters is marked with sutures.

perineum. Care is taken to ensure that the rectum is not twisted. The clip is removed from the rectal fistula and the fistulous tract is sutured to the edges of the skin incision with interrupted absorbable sutures. Laparoscopically firm traction on the rectum invaginates the rectoanal anastomosis and inverts the neoanal skin to a position under the external sphincters. The taut rectum is sutured to the presacral fascia with permanent sutures. The external sphincter is stimulated, and an anal wink is demonstrated. The trocars are removed and the incisions are closed.

Results

The author has treated eight infants with high imperforate anus using a laparoscopic assisted approach. Although we performed most of these procedures after a diverting sigmoid colostomy, we have performed several procedures entirely in one stage. We currently prefer the staged approach as it decompresses the colon for the pull-through procedure. I allow ample time postoperatively to dilate the neoanal tract prior to closure of the colostomy. As this technique evolves, it will undoubtedly be performed more frequently as a single stage procedure. Since our oldest patients are currently under one year of age, we have no data regarding continence in these patients. However, we feel that preserving the normal anorectal musculature and placing sensate skin within the control of the sphincters may be helpful in the development of sophisticated fecal continence.

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Laparoscopic Treatment of Ileocolic Intussusception

Steven S. Rothenberg

Introduction

As experience with minimally invasive surgery (MIS) in children becomes greater the ability to apply these techniques to a more diffuse range of disease processes has evolved. While laparoscopy's role in the treatment of gallbladder disease or gastroesophageal reflux has been relatively accepted, the application of MIS in other areas such as neonatal surgery or more advanced bowel surgery is still questioned. However the advantages of this approach including access to the entire peritoneal cavity through two or three small 3-5 mm incisions makes this approach very attractive, especially in cases where large incisions would be required to gain adequate visualization and access to perform the necessary surgical manipulations. To that end, the application of MIS for the evaluation and treatment of intussusception can significantly decrease the morbidity and recovery associated with traditional open surgery to these patients.

Intussusception

Ileocolic intussusception which has failed hydrostatic reduction has routinely been treated through a right lower quadrant transverse incision. In cases where the lead point is still in the left colon the incision may need to be extended past the midline. By approaching intussusception laparoscopically the lead point can be visualized and manipulated through three 3 mm or 5 mm trocars. This approach also guards against the occasional instance where the reduction appears to be incomplete on barium enema but after the induction of general anesthesia the intussusception is found to be completely reduced at exploration.

Technique

The patient is placed supine near the foot of the table. As with malrotation the surgeon is at the patient's feet; however depending on the position of the intussusception, the surgeon may rotate to the right or the left of the table depending on the position of the lead point. The basic principle is for the surgeon to be in line with the camera, the intussusceptum, and the video monitor to prevent paradoxical motion while operating. The abdomen is insufflated through a umbilical ring incision and a trocar is inserted to act as a camera port. Two other trocars are placed in the right lower quadrant and the left mid to upper quadrant to allow for manipulation of the bowel (Fig. 17.1). Occasionally it is necessary to move the camera to the left

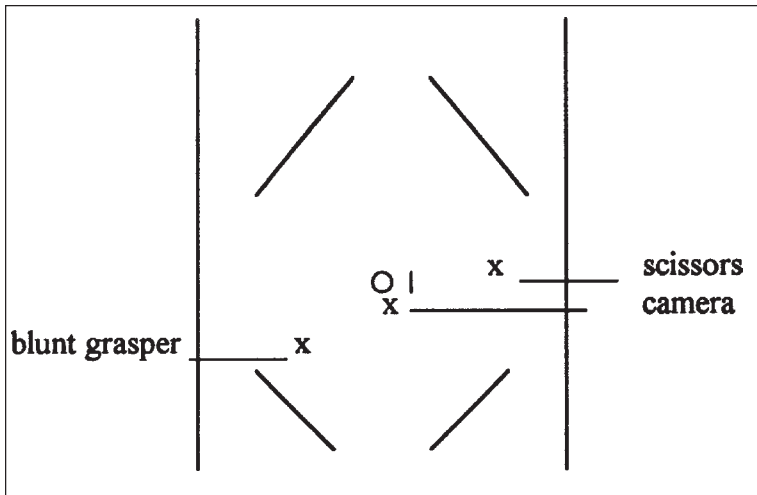


Figure 17.1. Trocar placement for approach to malrotation and intussusception.

upper quadrant port and operate through the other two, especially as the lead point reaches the ileocecal valve. Once the position of the intussusceptum is identified two atraumatic bowel clamps are used to attempt reduction. The initial technique is a milking maneuver using the two clamps to try and push the lead point retrograde, similar to the manual manipulation performed in open surgery. However in each case done to date the final reduction was achieved only after traction was placed on the terminal ileum to pull the lead point out of the cecum. Once complete reduction is achieved the appendix is removed in a similar fashion to that described for malrotation.

The average operative time for these cases has been under 40 minutes and there have been no bowel injuries or incomplete reductions. An NG tube has not been left in postoperatively and feeds are resumed on postoperative day one. The average hospital stay has been less than 2 days. The main concern voiced about this technique is the use of traction to reduce the intussusceptum and the risk of bowel injury. If the traction applied is at a constant and low pressure there appears to be no greater incidence of serosal tear than that encountered with manual reduction. Also the bowel is being observed under significant magnification and therefore any serosal tear should be identified earlier. Also the fact that the intussusceptum is being reduced in the peritoneal cavity with a moderate degree of external positive pressure as opposed to outside the abdomen with the mesentery and the bowel on a significant stretch, may actually aid in achieving a successful reduction. If reduction is unsuccessful the procedure can easily be converted to open and manual reduction or resection performed.

Conclusion

Laparoscopic evaluation and treatment of intussusception are clinically proven procedures. They appear to have the same benefits as other MIS including decreased pain and earlier recovery and hospital discharge. The added advantage in these two disease processes is that laparoscopic evaluation can be performed to ensure the presence of the radiographic abnormality and in most cases therapeutic correction can be achieved without committing to a large laparotomy incision. However the pediatric laparoscopist must recognize that these are advanced procedures and require delicate bowel manipulation. These procedures should not be attempted if the surgeon is not comfortable performing advanced procedures endoscopically or in cases where the patient clearly shows signs of compromised bowel or hemodynamic instability.

Laparoscopic Evaluation and Treatment of Rotational Anomalies

Hanmin Lee and Mark L. Wulkan

Introduction

Disorders of rotation and fixation of the intestine (rotational anomalies) may lead to the potentially life-threatening complication of midgut volvulus. In this chapter we will outline an approach to rotational anomalies that incorporates minimally invasive techniques. In order to understand the rationale for this approach, one must review the embryologic basis for malrotation and midgut volvulus.

The fetal midgut undergoes 270° counterclockwise rotation around the superior mesenteric artery (SMA) between 5 to 12 weeks of gestation. Duodeno-jejunal rotation is “under” the SMA, leaving the ligament of Treitz (LoT) to the left of midline and superior to the pylorus. Cecal rotation is “over” the SMA, leaving the cecum in the right lower quadrant. The bowel then becomes fixed to the retroperitoneum at the duodenum, and the ascending and descending colon throughout gestation. This process is well described and illustrated in other texts.

Faulty rotation or fixation occurs in approximately 1 in 500 live births and causes a broad spectrum of anatomic variations collectively termed rotational anomalies. These anatomic abnormalities range from incomplete descent and fixation of the cecum to complete non-rotation. The actual abnormality may vary significantly from patient to patient. It is possible to have isolated partial or complete abnormal rotation of the duodeno-jejunal segment or the cecal segment. Children with rotational anomalies present in a variety of fashions, including emesis, gastroesophageal reflux, abdominal pain, failure to thrive, constipation, and diarrhea. Many children present with the incidental finding of abnormal rotation during the workup of other gastrointestinal disorders. Midgut volvulus is the dreaded consequence of rotational anomalies and is the most common surgical cause of bilious emesis within the first month of life. Midgut volvulus develops when the midgut twists around the narrow mesenteric base that results from the rotational abnormality. Not all rotational anomalies result in a narrow mesenteric base. The symptoms that the patient is having may be the result of duodenal obstruction from Ladd's bands that usually extend across the duodenum, or obstruction from intermittent partial volvulus.

Rotational abnormalities are diagnosed by an upper gastrointestinal series (UGI) or a barium enema (BE). UGI is more sensitive and specific. The primary criteria for diagnosis of a rotational abnormality are the position of the LoT to the left of midline and superior to the pylorus.

The purpose of surgery (Ladd's procedure) should be to (1) reduce volvulus if it exists, (2) remove the presence of other obstructive lesions such as Ladd's bands or twists in the duodenum, (3) minimize the chance of volvulus by broadening the mesentery of the midgut, and (4) remove potential future diagnostic dilemmas by removing the abnormally located appendix. In this chapter, we outline our clinical approach towards children with rotational anomalies using minimally invasive techniques. We will focus mainly on children with rotational anomalies without midgut volvulus.

Rotational Anomalies without Volvulus

Children with rotational anomalies without volvulus usually present "electively" after an UGI is obtained. If the presenting symptoms are worrisome, such as bilious emesis in an infant less than one year old, one must proceed expeditiously as the patient may have intermittent volvulus, which the UGI did not detect. A substantial subset of children with rotation anomalies is diagnosed with "asymptomatic" malrotation on upper or lower intestinal contrast studies. Upon further review, many of these children in fact have symptoms that may be attributable to their rotational anomalies that precipitated their radiographic evaluation. Many other patients with rotational anomalies have nonspecific complaints such as abdominal pain, nausea, weight loss or failure to thrive, constipation, gastroesophageal reflux, or diarrhea. A small subset of children may have a truly asymptomatic rotational anomaly. Operative intervention is somewhat controversial in this group, especially in older children; however, most authors recommend repair.

On upper gastrointestinal series, several findings suggest the possibility of a rotational anomaly. The fourth portion of the duodenum will not be found in the normal position, which is to the left of the spine and at or superior to the level of the pylorus. The small bowel may be found predominantly on the left side of the abdomen. Additionally, the duodenum may be tortuous in its course or have an obstruction. A contrast enema study may show the colon predominantly in the left side of the abdomen without the usual course of the splenic flexure in the left upper quadrant, the hepatic flexure in the right upper quadrant and the cecum in the right lower quadrant. It is difficult, if not impossible, to determine the width of the mesentery on radiographic studies.

The purpose of treatment of rotational anomalies is to prevent midgut volvulus and relieve any obstructions. This is accomplished by (1) minimizing the chance of volvulus by broadening the mesentery of the midgut (2) removing the presence of other obstructing lesions such as Ladd's bands or twists in the duodenum and (3) removing potential future diagnostic dilemmas by removing an abnormally located appendix. These goals should be achieved within the context of minimizing hospital stay, discomfort, and complications. We have developed an algorithm for these patients who have rotational anomalies without volvulus using initial laparoscopic evaluation. (Fig. 18.1)

As depicted in Figure 18.1, patients with rotational anomalies without midgut volvulus initially undergo laparoscopic evaluation. We typically use three 3.5 mm ports (see Fig. 18.2). The abdomen is accessed through the umbilicus. All infants are accessed using the Veress technique. If the umbilicus is incised vertically, directly at its base, there is often a small fascial defect that makes the placement of the Veress needle very easy and safe. Placement of the Veress needle in the peritoneal cavity is

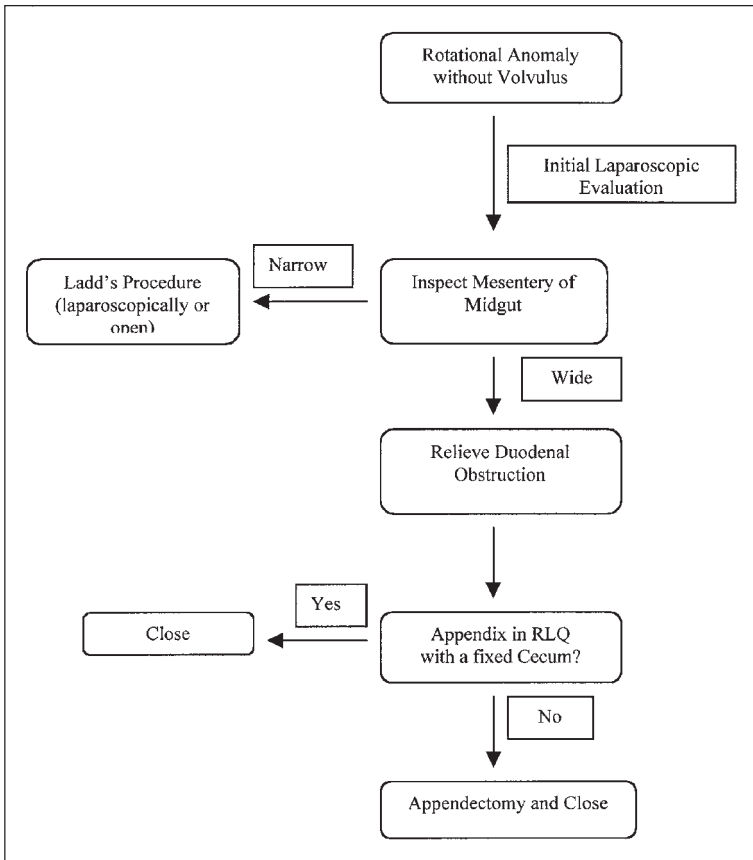


Figure 18.1. Algorithm for patients with rotational anomalies without volvulus.

confirmed using the “blind-man’s cane” technique. The needle is swept under the abdominal wall at least 90°. If there is no impediment to this motion, it is safe to insufflate the abdomen. We typically inflate to 12 mm Hg for children less than 5 kg. Many of these children have associated congenital anomalies, the most common being congenital heart disease. It may be necessary to use lower pressures in these children. There is evidence that end-tidal CO₂ measurements in children with congenital heart disease may not accurately reflect the arterial partial-pressure of CO₂.

A 30° laparoscope is placed through the umbilical port. Working ports are then placed on the right and left side of the abdomen. The left-sided port should be placed near the level of the umbilicus or slightly higher. The right-sided port should be placed below the level of the umbilicus. This will allow the apex of visualization to be in the right upper quadrant at the duodenum. Port placement may be modified as needed for different size children. Accessory ports may be placed in the left

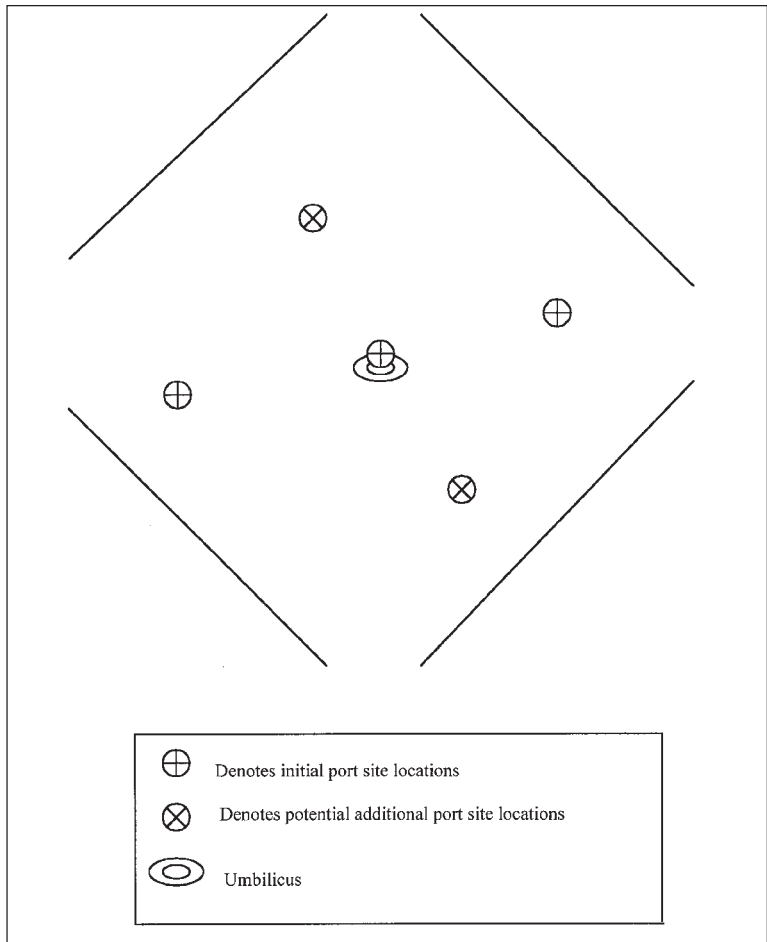


Figure 18.2. Port placement for patients with rotational anomalies without volvulus.

lower or right upper quadrant as needed. In our experience, this is usually not necessary. The first step of the procedure is inspection of the right upper quadrant. If there is volvulus present, it may be necessary to convert to an open Ladd's procedure, depending upon the skill and comfort level of the operating surgeon. The second and third portion of the duodenum should be inspected. If the duodenum is tortuous in its course or Ladd's bands are present, then these possible sources of obstruction are corrected. This is done using blunt and sharp dissection with the scissors. Next the LoT is identified and the root of the mesentery is examined. If the base of the mesentery is broad, no further dissection is needed. This is best accomplished by examining the width of mesentery between the duodenum and the cecum. If the

ileocolic segment is closely associated with the duodenum, it is likely that there is a narrow mesenteric base.

If the mesenteric base is narrow, the surgeon should proceed with a standard open Ladd's procedure or laparoscopic Ladd's procedure. Broadening the mesentery is more challenging, and the placement of an additional port may be necessary if the surgeon is to continue laparoscopically. Frequent repositioning of the bed (Trendelenburg, reverse Trendelenburg, left side up, right side up) may be necessary in order to adequately view the mesentery. If the anatomy is confusing, or the dissection difficult, we recommend conversion to a laparotomy.

Some surgeons are concerned that the adhesions formed during an open Ladd's procedure may be beneficial in preventing recurrent volvulus. Unfortunately there are no trials with long term follow-up.

Finally, the appendix is removed, unless it is in the correct anatomic position in the right lower quadrant. The appendectomy removes the possibility of future diagnostic difficulties secondary to appendicitis. The appendectomy may be performed in the standard laparoscopic fashion, or one may bring the appendix out through the umbilical port and perform an inversion or standard appendectomy. It is the authors' preference to perform an extracorporeal inversion appendectomy. Due to the mobility of the colon in these children this is very easily accomplished.

Malrotation with Midgut Volvulus

The presence of midgut volvulus increases urgency and difficulty of surgery for rotational anomalies. The most important component of surgery for midgut volvulus is reduction of the volvulus and sparing as much viable small bowel as possible.

If volvulus is present, the difficulty of laparoscopic intervention is greatly increased. A technique that is useful in reducing the volvulus is to identify the proximal jejunum and run the small intestine. This will effectively reduce the volvulus, and the bowel viability can be assessed at the same time. Reducing the entire volvulus en mass as with an open procedure is difficult. We have a very low threshold for converting to an open procedure if midgut volvulus is found, and do not recommend continued minimally invasive intervention in the hands of all but the most experienced laparoscopists. The remainder of the Ladd's procedure is performed as described above.

Conclusion

Rotational anomalies constitute a broad spectrum of anatomic variants ranging from incomplete fixation of the cecum to complete nonrotation. Analogously, presentation can range from incidental finding to constipation or occasional feeding difficulties to midgut volvulus. Radiographic studies frequently do not distinguish the anatomic variants of rotational anomalies. The described techniques are particularly helpful in patients who have minor rotational anomalies and abnormal radiographs. Laparoscopy has given the clinician a valuable tool with which to diagnose rotational anomalies and correct potentially obstructing lesions with minimal surgical trauma to the patient.

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Minimally Invasive Surgery for Pediatric Cancer

Andrew M. Davidoff

Introduction

In 1911 the Swiss surgeon H. C. Jacobaeus reported the use of diagnostic laparoscopy in a large number of patients with a variety of conditions including cancer. Little progress was made however in developing the role of minimal access surgery in malignant disease for over 70 years. The technologic advances in the late 1980s with the introduction of miniaturized video cameras resulted in a dramatic escalation in the use of minimally invasive surgery. Its use in patients with malignancies has been slower to evolve, however, but is gaining greater acceptance for use in adult cancer patients.

As the general use of minimal access surgery in pediatric patients has lagged behind its use for adult patients, so too has its use in infants and children with malignancies. It has not, as yet, been widely accepted for more than diagnostic purposes and there are only a few reports describing the use of minimal access surgery in infants and children with cancer. Several concerns have contributed to the limited use of minimal access surgery in these patients. (1) Loss of tactile sensation. This is important when trying to evaluate the thoracic or peritoneal cavities for tumor spread and lymph node involvement when, for example, attempting therapeutic resection of pulmonary metastases in patients with osteosarcoma or accurately staging a patient with an abdominal neuroblastoma. (2) Tumor spill. Spill of a Wilms tumor, for example has a significant impact on tumor staging, therapeutic approach and, ultimately, prognosis. In addition, a number of pediatric tumors, such as pleuropulmonary blastoma or malignant thymoma are not responsive to treatment modalities other than surgical resection. Tumor spill often leads to local recurrence that can be ultimately very difficult to treat. (3) Tumor recurrence at trocar sites. Although there are few reports of this phenomenon in adult patients, pediatric surgical oncologists continue to be concerned about this issue. There have been instances in cases of intraoperative tumor rupture where Wilms tumor has recurred in laparotomy scars. (4) Removal of tumor specimens from the abdominal or thoracic cavities. In order to retain the benefits of the minimal access approach, specimens are often morcellated so that they can be removed through the smaller incisions. Although it has been shown that the use of a tissue morcellator does not interfere with adequate histologic evaluation of the tissue, concerns remain, especially with regard to the ability to assess the margins of resection and gross anatomic relationships.

Nevertheless, as technology continues to advance and the skill and comfort of pediatric surgeons with minimally invasive approaches increase, its use for children with cancer is likely to increase also. The general benefits of a minimally invasive approach, such as decreased postoperative recovery time, are particularly important for pediatric patients with malignancy. These patients need a prompt, accurate diagnosis and a short recovery time so that treatment can be initiated in a timely fashion. Long-term discomfort from surgical procedures may also be diminished, especially, for example, for children with sarcomas who may undergo multiple procedures for resectable, lung metastases. Clearly, carefully controlled randomized studies are needed to help determine the benefits and drawbacks of this new, evolving methodology.

Indications

In 1995 the Surgical Discipline Committee of the Children's Cancer Group published the two-year experience of the group members with minimally invasive surgery in children with cancer. The most common indications for laparoscopy were for the evaluation of a new mass, staging, second-look procedures, and for the assessment of tumor resectability. The most common indications for thoracoscopy were to rule out metastatic disease, evaluation of a new mass, lung biopsy in patients with respiratory failure or pulmonary infiltrates, and to evaluate thoracic/chest wall lesions for resectability. In 1998 the experience with minimal access procedures in infants, children and young adults at Memorial Sloan-Kettering Cancer Center was published (Table 19.1). Nearly all of the laparoscopic or thoracoscopic procedures performed there during the seven-year period were tumor or lymph node biopsies. Finally, in 1999, Holcomb surveyed a dozen experts in pediatric surgical oncology and minimally invasive surgery for the Surgical Section of the American Academy of Pediatrics about their management practices for children with cancer. The clearest indication for the use of minimally invasive surgery for this group was biopsy of lesions in the chest or abdomen. Resection of solid organs with tumor was less enthusiastically supported.

Biopsy of Solid Tumors

The most common extracranial, solid tumors of infancy and childhood are listed in Table 19.2. Most of these malignancies are treated with a multimodal approach of which surgery is an important component. Because these tumors are usually sensitive to neoadjuvant chemotherapy, the treatment paradigm for large tumors usually begins with an initial biopsy with subsequent delayed primary resection. Therefore biopsy of a new mass in a child either by a laparoscopic or thoracoscopic approach is a common indication. These can often also be approached by a radiographically guided percutaneous biopsy although direct visualization of the lesion often gives additional anatomic detail and may provide visual confirmation of adequate hemostasis. In addition, with the current increasing emphasis in Children's Oncology Group protocols on the procurement of tumor tissue for biologic studies, the laparoscopic or thoracoscopic approach may be increasingly favored for its ability to obtain more tissue while remaining minimally invasive. The diagnostic accuracy for minimal access procedures has typically been high, generally being reported in the range of 85-100%. The avoidance of large incisions that often led to postoperative ileus and atelectasis, in conjunction with this high diagnostic accuracy permitting

Table 19.1. Minimal access procedures in infants, children, and young adults with pediatric malignancies: diagnoses

<i>Diagnosis</i>	<i>Laparoscopy</i>	<i>Thoracoscopy</i>
Leukemia	13	4
Lymphoma	10	9
Desmoplastic Small Round Cell Tumor	9	2
Ewing's	1	8
Rhabdomyosarcoma	2	5
Osteosarcoma	0	5
PNET	1	4
Neuroblastoma	2	3
Other	8	7

Adapted from The Journal of Laparoendoscopic and Advanced Surgical Techniques, Table 2, p.291. Mary Ann Liebert, Inc., The application of minimal access procedures in infants, children, and young adults with pediatric malignancies, Saenz NC, Conlon KCP, Aronson DC, and LaQuaglia MP. Reprinted with permission.

Table 19.2. The histologic types of solid tumors accessioned (most frequently in 1998 at St. Jude Children's Research Hospital), total number of cases = 129

<i>Diagnosis</i>	<i>Percentage of Cases</i>
Neuroblastoma	15
Retinoblastoma	12
Rhabdomyosarcoma	10
Osteosarcoma	9
Wilms Tumor	9
Neuroepithelioma	8
Other	37

the prompt initiation of appropriate chemotherapy, is a significant advantage. In addition diminished intraperitoneal and intrathoracic adhesions after a minimally invasive biopsy may be advantageous when performing second look or delayed primary surgery.

An exception to this approach of biopsy of large tumors is Wilms tumor. These renal neoplasms may in fact be resectable primarily even when quite large because they do not tend to invade surrounding structures. This is important because patients with completely excised Wilms tumor (stage I or II) are treated with a significantly milder treatment regimen than those of higher stage. Yet patients who undergo an initial transabdominal biopsy are treated as stage III because of the inevitable tumor spill into the peritoneal cavity that results from the tumor biopsy and, therefore, receive a more intensive regimen.

Staging

Although there have been significant improvements in the radiographic assessment of the extent of malignancy, discrepancies between radiographic and surgical

staging can occur. With the development and acceptance of minimal access surgery may come a greater emphasis on the need for surgical/pathologic staging. Accurate staging will become even more important as pediatric protocols attempt to decrease the intensity of treatment while maintaining high rates of cure currently achieved for many pediatric malignancies. Lymph nodes in the chest and abdomen can be easily sampled through a minimally invasive approach to stage thoracic and abdominal tumors. Occasionally intraabdominal lymph nodes may need to be evaluated for extraabdominal primaries also. For example, iliac lymph nodes need to be evaluated in patients with testicular tumors when an abnormality is detected on CT scan. This is important for staging in rhabdomyosarcoma and can, additionally, be therapeutic for patients with a germ cell tumor of the testis.

During staging the liver surface can be inspected for small, metastatic deposits and biopsy performed under direct vision, with the confirmation that hemostasis has been achieved. The peritoneal and pleural surfaces, sites of tumor spread not always accurately assessed by imaging studies, can be completely evaluated for disease. Finally, nodules of the pulmonary parenchyma, detected by CT as part of a staging evaluation, can be biopsied to confirm or exclude the presence of metastatic disease. This determination can have a significant impact on the treatment plan and ultimate prognosis for children with cancer.

Radiographic imaging has shown an error in staging when compared to surgical staging of approximately 30% for children with Hodgkin's disease. However, because treatment of these patients has been so successful, with a high cure rate and low morbidity, surgical staging is no longer a part of the routine staging of these children. However, there is still interest in a minimally invasive surgical approach to the evaluation of nodal regions with equivocal CT or lymphangiogram findings in cases where disease stage and, consequently, treatment will be significantly impacted. This is particularly true when distinguishing stage II from stage III Hodgkin's disease where the use of alkylating agents and radiation therapy is being considered. Whether routine, complete surgical staging will return to favor as the minimal morbidity and diagnostic accuracy of laparoscopy in evaluating the liver, spleen and lymph nodes is recognized, is uncertain.

Determination of Resectability

The determination of resectability of a primary tumor is a very useful indication for laparoscopy or thoracoscopy. In the CCG experience this was done most often for the evaluation of liver tumors and tumors of the chest wall. The minimally invasive approach can be used to evaluate anatomic relationships, invasion of vital structures and to assess whether multifocal disease is present. If a tumor is determined to be unresectable, a biopsy can be easily performed at the same time if this has not already been done. In addition to evaluating the extent of liver or thoracic disease, laparoscopy may be particularly helpful in determining the resectability of large pelvic tumors. Their relationship with the bladder, uterus, rectum and iliac vessels can be assessed. If the tumor is found to be ovarian in origin an attempt at primary resection may be more aggressively pursued as even large tumors are usually resectable.

Second-look, Recurrence, Metastatic Disease

Second-look operations can be performed even after a primary open resection. Tumor recurrence both locoregional and metastatic can be documented through a minimal access approach. This has been done most often for pulmonary metastases and retroperitoneal sites. Because pulmonary metastases are usually peripheral lesions they can be approached easily by thoracoscopy. In certain histologic types, resection of metastatic lesions may be both diagnostic and therapeutic, favorably influencing long-term survival. One drawback however to the thoracoscopic approach is the inability to palpate the lung to exclude the presence of smaller metastatic foci. It is unclear at this time however whether failing to identify and resect these lesions early will impact on patient survival.

Infectious and Other Treatment Associated Complications

Pediatric cancer patients frequently undergo intensive, multimodal therapy and a number of complications that require surgical intervention can arise during the course of their treatment. Many of these can be dealt with using a minimally invasive approach. Patients will often become anorexic as a result of their treatment and may benefit from a laparoscopic gastrostomy tube placement. Children who are unable to tolerate enteral feeds of any type and require TPN occasionally develop cholelithiasis as a consequence. Laparoscopic cholecystectomy can be performed in these patients for symptomatic stones or for acute cholecystitis. Patients with brain tumors may develop symptomatic gastroesophageal reflux. If the reflux is refractory to medical management they may benefit from a laparoscopic Nissen fundoplication. Laparoscopic oophoropexy is often performed for females who are to undergo abdominopelvic irradiation. Finally, as cancer patients, these children are immunosuppressed both because of their malignancy as well as their treatment. Minimally invasive surgery can be a very useful technique for evaluating lesions seen on radiographic work-up. Diagnostic tissue can be obtained to distinguish among tumor, a benign process and an infectious process and tissue for culture obtained to identify particular insidious organisms. This situation arises most frequently with lesions (or diffuse processes) of the lung, in which a thoracoscopic lung biopsy can be performed, but may occur in the liver or retroperitoneum.

Specific Procedures

Laparoscopy

A palpable abdominal mass is the most common presenting finding of malignant solid tumors in children. However, the differential diagnosis for an abdominal mass in a child is extensive; tumors are only a small part of that list. The location of the mass and the age of the patient (Table 19.3) are important when considering possible etiologies. Of masses that are tumors, the distribution of histologic types seen at one institution, the Institut Gustave-Rousy, is shown in Table 19.4. Once again tumor location and patient age influence the spectrum of cancers likely to occur (Table 19.5).

Lymphadenectomy

With appropriate exposure and careful dissection, most lymph node areas within the abdomen are accessible through a laparoscopic approach. The most common

Table 19.3. Etiology of abdominal masses by location

Right upper quadrant	Periumbilical
Liver	Intestine
Hepatomegaly	Omental/mesenteric cyst
Hepatitis	Intestinal duplication
Vascular anomaly	Obstruction
Tumor	Midgut volvulus
Gallbladder	Lymphangioma
Hydrops	Constipation
Cholecystitis	Gaseous distention
Gallstones	Ascites
Biliary tree	Right lower quadrant
Obstruction	Intestine
Choledochal cyst	Abscess (appendix, Crohn's disease)
Intestine	Intussusception
Duodenal atresia	Meckel's duplication cyst
Pyloric stenosis	Phlegmon
Duplication	Lymphoma
Duodenal hematoma	Inguinal hernia
Left upper quadrant	Ovary/testis
Spleen	Torsion
Splenomegaly	Cyst
Cyst	Ectopic pregnancy
Tumor	Teratoma (dermoid)
Epigastric	Tumor
Stomach	Undescended testis
Gastric bezoar	Left lower quadrant
Gastric volvulus	Ovary/testis (see Right lower quadrant)
Duplication	Intestine
Tumor	Constipation
Pancreas	Sigmoid volvulus
Pseudocyst	Hypogastrium
Pancreatitis	Uterus
Duplication	Hydrometrocolpos
Right/left mid-abdomem	Pregnancy
Kidney	Congenital anomaly
Hydronephrosis	Bladder
Wilm's tumor	Obstruction
Cystic kidney disease	Posterior urethral valves
Congenital anomaly	
Adrenal	
Neuroblastoma	
Pheochromocytoma	
Hemorrhage	

Adapted from Clinical Pediatric Gastroenterology. Churchill Livingstone, Chapter 1, page 2, 1998; Liacouras, CA, Abdominal Masses. Reprinted with permission.

sites are iliac, periaortic/pericaval, portal, celiac and mesenteric. Access to the iliac lymph nodes is achieved by incising the posterior peritoneum lateral to the vessels. Using careful sharp and blunt dissection the lymph nodes and adipose tissue are identified and separated from the adjacent vessels. To recover the higher periaortic

Table 19.4. Relative incidence of retroperitoneal tumors in 442 cases

Retroperitoneal tumors (442 cases)	Number of patients
Kidney	
Wilm's tumor	202
Other malignant tumors	10
Benign tumors	18
Sympathetic tumors	
Neuroblastomas with metastases at	
Presentation	215
Neuroblastomas without metastases	60
Neuroblastomas (IV's)	15
Ganglioneuromas	5
Adrenocortical tumors	7
Malignant lymphomas	65
Liver	
Benign tumors	9
Malignant tumors	14
Ovary	
Dysgerminomas	4
Teratomas	27
Embryonic sarcomas	22
Other	9

Data from the Institut Gustave-Roussy as presented in Shweisguth O, ed. Solid tumors in children. New York: John Wiley & Sons, 1982. Reprinted with permission.

and pericaval lymph nodes, the colon on the ipsilateral side must be mobilized. The lateral peritoneal attachment is incised. This should be done up to the hepatic or splenic flexure, to ensure adequate exposure. Positioning the patient in a near-lateral position and retracting the cecum or sigmoid medially with an endoscopic Babcock will assist the exposure. One must be careful not to dissect into the colonic mesentery and to avoid injury to the ureter and gonadal and iliac vessels. The majority of the dissection is done bluntly. Small perforating vessels and lymphatics are controlled with electrocautery or hemoclips. Some surgeons prefer to stand on the contralateral side of the patient while performing a periaortic lymph node dissection, and face down toward the pelvis, while others prefer to operate from between the patient's legs and face in a cephalad direction. Celiac nodes are approached through a window made in the lesser omentum superior to the lesser curvature of the stomach. Portal lymph nodes can often also be sampled with this approach or by following the cystic duct from the gallbladder down to the porta hepatis. Specific mesenteric lymph nodes may be difficult to sample especially in children since there are normally numerous enlarged lymph nodes in this region that are not pathologic. These are obtained by sharp dissection of the overlying peritoneum and careful dissection in the mesentery.

When preoperative imaging dictates that a specific node or nodes be sampled, it is often of great benefit to have these localized by an interventional radiologist to help in their identification at the time of laparoscopy, thereby ensuring that the appropriate one(s) are sampled. This can be done by injecting such agents as methylene blue

Table 19.5. Predominant pediatric cancers by age and site

Tumors	Newborn (<1 year)	Adolescent and Young Infancy (1 – 3 years)	Child (3 – 11 years)	Adult (12 – 21 years)
Thoracic	Neuroblastoma Teratoma	Neuroblastoma Teratoma Rhabdomyosarcoma	Lymphoma Neuroblastoma Rhabdomyosarcoma	Lymphoma Ewing's sarcoma
Abdominal	Neuroblastoma Mesoblastic nephroma Hepatoblastoma Wilm's tumor (> 6mo)	Neuroblastoma Wilm's tumor Hepatoblastoma Leukemia	Neuroblastoma Wilm's tumor Lymphoma Hepatoma	Lymphoma Hepatocellular carcinoma Rhabdomyosarcoma
Gonadal	Yolk sac tumor of testis (endodermal sinus tumor) Teratoma Sarcoma botryoides Neuroblastoma	Rhabdomyosarcoma Yolk sac tumor of testis Clear cell sarcoma (kidney)	Rhabdomyosarcoma	Rhabdomyosarcoma Dysgerminoma Teratocarcinoma, teratoma Embryonal carcinoma of testis Embryonal carcinoma and endodermal sinus tumors of ovary

Adapted from Pizzo PA, Poplack DG: Principles and Practice of Pediatric Oncology, Chapter 6, p. 136, Table 6-7, Clinical assessment and differential diagnosis of the child with suspected cancer, Stueber CP and White ME. Third Edition with permission of the publisher.

or India ink into the nodes under radiographic guidance. When a lymphangiogram has led to the detection of an abnormal lymph node, the node can be localized at the time of laparoscopy with the guidance of fluoroscopy since the contrast material will remain within the lymph node for a very long time.

Hepatic Resection (see Chapter 20)

Primary tumors of the liver are fairly rare in children although most are malignant. The two most common histologic types are hepatoblastoma (infants and young children) and hepatocellular carcinoma (older children and adolescents). Less common hepatic malignancies include mesenchymoma, rhabdomyosarcoma, and angiosarcoma. Secondary metastasis to the liver can occur from nearly every tumor type. Laparoscopy is extremely useful in the evaluation of liver lesions. It can be helpful in performing a directed biopsy of lesions identified by preoperative imaging or for inspection of the liver to exclude the possibility of missed lesions. The biopsy can be performed using a variety of different instruments including a Tru-cut needle, cup forceps, electrocautery or "hot" scissors, or an endoscopic linear stapler. The laparoscopic ultrasound probe can be very useful in localizing lesions that are within the parenchyma. The other common indication for laparoscopy in children with liver lesions has been the evaluation of a lesion for resectability. Although formal, anatomic laparoscopic liver resections (e.g., lobectomy) have been described for adult patients, none has yet been reported in pediatric patients with cancer. We have performed a laparoscopic resection of segments 2 and 3, however, in a child with a benign mesenchymal tumor of the liver.

Adrenalectomy (see Chapter 22)

The differential of an apparently solid adrenal mass, especially in infants, can include such benign processes as hemorrhage, infection and congenital adrenal hyperplasia. The most common solid neoplasm is neuroblastoma although pheochromocytoma and adrenocortical adenomas and carcinomas can occur. Metastases to the adrenal gland are rare in children. A few small series have described laparoscopic adrenalectomy in children with neuroblastoma. Careful patient selection was done in these series, choosing patients with small lesions that were likely to have favorable biologic characteristics. One must remember that careful evaluation of lymph nodes is very important in the staging and, ultimately the treatment of these patients. Those patients likely to have a ganglioneuroblastoma or ganglioneuroma may be the best candidates for a laparoscopic approach. A laparoscopic resection of an adrenal pheochromocytoma in a child has also been reported. In cases where a pheochromocytoma is suspected, appropriate preoperative preparation is, of course, essential.

Nephrectomy (see Chapter 23)

Although structural abnormalities of the genitourinary tract are common causes of abdominal masses, particularly in infants, solid lesions arising in the kidney are usually neoplastic. Mesoblastic nephroma accounts for the majority of renal masses in children younger than 1 year of age. For children older than the age of 1, nearly all solid tumors arising in the kidney are Wilms' tumors. Renal cell carcinoma, clear-cell sarcoma and rhabdoid tumor of the kidney are other less common tumors in children. Because of the concerns of upstaging a Wilms tumor mentioned previously, a laparoscopic biopsy of a kidney mass is not recommended. Additionally,

perhaps because these tumors are often quite large, and because of the implications of tumor spill, there are no reports of a laparoscopic nephrectomy for Wilms tumor.

Oophorectomy/Oophoropexy

Most ovarian masses presenting in infancy and childhood are neoplastic. Fewer than one-third of these tumors will be malignant although the risk of malignancy increases with increasing age to a peak incidence between 10 and 14 years of age. Neoplasms of germ cell origin are the most common histologic type in children. Tumors of the ovary, both benign and malignant, are currently one of the few pediatric neoplasms completely resected using a laparoscopic approach. This is probably due to the fact that these tumors are typically narrow based, rarely locally invasive, intraabdominal tumors that are easily resected and staged laparoscopically. Staging is accomplished by (1) collecting ascites or peritoneal washings, (2) inspecting the peritoneal surface and liver, (3) performing a unilateral salpingo-oophorectomy, (4) performing an omentectomy and iliac node sampling and (5) inspecting the contralateral ovary and biopsying suspicious lesions. For malignant tumors, the involved ovary and ipsilateral fallopian tube can usually be freed by firing an endoscopic linear stapler across the suspensory ligament of the ovary, the broad ligament and the cornu of the uterus. Some controversy exists regarding the surgical management of benign ovarian tumors as to whether an oophorectomy should be performed or an attempt made at preserving uninvolved ovarian tissue to save ovarian follicles. As always when performing a laparoscopic procedure, the conduct of the operation should proceed as it would if being done in an open manner. If an ovarian tissue-preserving approach is selected, the plane between the tumor and the splayed out ovarian tissue is incised either sharply or with electrocautery. Then with a grasper holding the surrounding edge of ovarian tissue, the tumor is shelled out from within. Occasionally bleeding sites from the raw surface of the ovary will require cauterization. The remaining ovarian tissue can then be sutured in a folded manner to prevent exposure of the raw surface.

Children with cancer, particularly patients with Hodgkin's disease and medulloblastoma often receive irradiation that includes the pelvis. This puts these patients at risk for ovarian failure. In order to decrease the incidence of this complication, these patients are often referred for oophoropexy. This procedure is ideally suited for a minimal access approach as it can be accomplished easily, quickly and with minimal discomfort for the patient. The ovaries can either both be secured in a retrouterine midline position or separately, laterally up and out of the pelvis. When placed in a retrouterine position separate sutures are passed though the upper and lower poles of each ovary which are then transfixed to the uterus at the level of the cervix. It is often helpful when performing this procedure to temporarily place the uterus in an anteverted position. This can be accomplished by either placing a uterine manipulator or sponge stick in the vagina, passing a temporary traction suture percutaneously through the abdominal wall to the uterus and back out or placing an additional trocar through which an instrument such as a Babcock or liver retractor can be passed. Clips are used to mark the location of the transposed ovaries.

Retroperitoneum

In children primary tumors of the retroperitoneum are most commonly neuroblastomas although rhabdomyosarcomas and germ cell tumors can also occur. In addition nearly all neoplasms of childhood can present with bulky lymphadenopathy of the retroperitoneum. The approach for biopsy of these lesions varies with the size and position of the lesions and must be individualized. Large masses of the retroperitoneum are usually visualized in the course of routine diagnostic laparoscopy. Smaller lesions of the retroperitoneum may require mobilization of either the right or left colon. Occasionally lesions at the base of the mesentery can be approached directly without reflecting the colon. It may be of benefit to have small lesions localized preoperatively with the assistance of an interventional radiologist. A percutaneous needle localization can be performed as can injection of dye such as methylene blue or India ink.

Splenectomy (see Chapter 14)

Splenectomy is rarely performed in pediatric cancer patients because of concerns regarding overwhelming post-splenectomy sepsis and extreme thrombocytosis. Splenectomy may be of some benefit in children with hypersplenism or painful splenomegaly, or to reduce a leukemic burden prior to ablative therapy. It is uncertain whether splenectomy in children with CML may remove a pool of cells destined to undergo blast transformation. As mentioned earlier, surgical staging, including splenectomy, for children with Hodgkin's disease is currently infrequently performed.

Thoracoscopy

The mediastinum is the site of most intrathoracic masses in children. Localization of the mass to one of the mediastinal compartments greatly effects the differential diagnosis (Table 19.6). Most lesions of the pulmonary parenchyma are either secondary to infection, inflammation or are metastases although primary tumors of the bronchopulmonary tree can occur (Table 19.7).

Mediastinum

Localization of a mediastinal mass should be done by preoperative PA and lateral chest x-rays and/or chest CT scan. This is important not only in focusing the

Table 19.6. Mediastinal tumors

Anterosuperior Mediastinum	(42%)
Lymphoma	
Teratoma	
Thyroid lesions	
Thymoma	
Middle Mediastinum	(18%)
Bronchogenic cyst	
Pericardial cyst	
Lymphoma	
Posterior Mediastinum	(40%)
Neurogenic tumors	
Lymphoma	

Table 19.7. Primary bronchopulmonary tumors in 230 children: Classification by type of tumor

Type of Tumor	No. Patients (230 total)
Benign	64
Inflammatory pseudotumor	45
Neurogenic tumor	9
Leiomyoma	6
Mucous gland adenoma	2
Myoblastoma	2
Possibly Malignant	80
Pulmonary hamartoma	15
Bronchial adenoma	65
Malignant	86
Bronchogenic carcinoma	47
Pulmonary blastoma	14
Leiomyosarcoma	9
Rhabdomyosarcoma	6
Hemangiopericytoma	3
Lymphoma	2
Teratoma	1
Plasmacytoma	1
Myxosarcoma	1

Adapted from Ann Thorac Surg 36(1):108-119, July 1983. Elsevier Science, Inc. Hartman GE, Shochat SJ: Primary pulmonary neoplasms of childhood: a review. Printed with permission of the publisher.

preoperative differential diagnosis but for positioning the patient at the time of thoracoscopy and biopsy. Patients with lesions in the anterior mediastinum should be placed in a 45° lateral position while patients with lesions in the posterior mediastinum should be placed in a 135° lateral position. This will permit the lung to fall away from the area to be explored. Insufflation of CO₂ into the chest may also help to improve exposure by encouraging collapse of the ipsilateral lung, especially in smaller patients in whom a dual-lumen endotracheal tube cannot be easily used. Trocars should be placed some distance away from a target area in order to ensure maximal maneuverability with the working instruments. Once a lesion has been localized, there are several different instruments available with which to obtain a biopsy. These include cup biopsy forceps and percutaneously placed tru-cut needles. One should consider aspirating a suspicious lesion with a small gauge needle prior to biopsy to ensure that the target is not a vascular structure.

Lung

As above, patients should be positioned so as to have the effect of gravity on the lung leave the surface of interest exposed. Again, insufflation of the chest in order to fully collapse the lung can be of great utility especially when trying to secure the lung parenchyma within the relatively small jaws of an endoscopic linear stapler to perform a wedge resection. The newly released endoscopic linear staplers which are longer and can be opened more widely are very useful when performing a

thoracoscopic lung biopsy. Although insufflation often helps to visualize pulmonary lesions, some that are just under the pleura may be more easily detected by observing a puckering effect on the pleural surface with the lung at least partially inflated. Localization of pulmonary lesions with dye or needle can often be invaluable when attempting to find these lesions at the time of thoracoscopy.

The role of thoracoscopy for children with pulmonary metastases from osteosarcoma, in whom metastasectomy may be therapeutic, is controversial. It is well known that CT scans will underestimate the number of metastases present and only by direct palpation of the pulmonary tissue can the extent of disease be adequately assessed. It is unclear whether early resection of these tiny lesions impacts patient survival, however. Holcomb's survey for the AAP suggests that most surgeons advocate open thoracotomy for these patients in order to palpate the lung.

At the LeBonheur Medical Center we have performed several thoracoscopic lobectomies in children but none in patients with malignant disease.

Selected Readings

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Laparoscopic Liver Surgery in Children

Kelly A. Kogut

The explosion in technology, instrumentation and expertise has expanded the applications of the laparoscopic approach to many procedures traditionally done open and has been applied to liver surgery. Many of these procedures require advanced laparoscopic surgical skills as well as experience in open liver surgery. Other procedures, such as evaluation of the liver in cases of abdominal malignancy and liver biopsy require minimal instrumentation and are within the reach of even the novice laparoscopic surgeon. This chapter describes how these methods can be applied to liver surgery in children.

Indications

The indications for biopsy and resection of liver masses are the same regardless of the approach, laparoscopic or open. Liver lesions requiring excision are uncommon in children. Benign masses such as focal nodular hyperplasia, adenoma, hamartoma and hemangioma are usually asymptomatic and therefore do not require removal unless the diagnosis is unclear. When the etiology of the mass is uncertain or if the mass becomes symptomatic biopsy and/or excision may be warranted.

Cystic liver lesions in children are usually congenital, solitary, simple cysts. They are usually asymptomatic unless they are rapidly expanding, infected, ruptured or have intracystic hemorrhage. In these situations they are best treated by simple unroofing because percutaneous drainage has a high rate of recurrence. Solitary liver cysts located anteriorly are the most amenable to laparoscopic fenestration, and results are generally excellent with very low rates of recurrence. Polycystic liver disease is more common in adults than in children although it may sometimes be seen in teenagers. These cysts may be located deeper within the parenchyma, involve a large proportion of the liver tissue, and are less amenable to the laparoscopic approach. Recurrence rates after fenestration for polycystic liver disease are high because decompression of superficial cysts may allow expansion of smaller and deeper cysts. Care must be taken not to confuse cysts, which have a blue appearance when transilluminated, with vascular structures, and ultrasound may help distinguish the two.

Various infectious lesions may involve the liver and at times require surgical drainage or excision. Pyogenic abscesses are usually successfully treated with antibiotics and percutaneous drainage, but surgical drainage may be needed if these methods fail to resolve the abscess. Cat scratch disease can result in multiple granulomas within the liver. Laparoscopic exploration and biopsy may be required for diagnosis. Perihepatic adhesions resulting from pelvic infections, Fitz Hugh Curtis, is a cause of right upper quadrant pain, and these adhesions are amenable to laparoscopic lysis.

Echinococcal cysts are rarely seen in the USA, and thus there is not a lot of experience dealing with these lesions. These cysts can pose some difficult problems. Excision risks spilling the parasitic debris and secondary echinococcal infection or anaphylactic reaction. Echinococcal infection causes a strong inflammatory response in the liver, and complex biliary fistulas may result. Two options exist for management. For large cysts or those located near large veins, sterilization of the cyst, aspiration, unroofing and omentoplasty can be performed. Smaller and anteriorly located cysts can be excised by pericystectomy with subsequent identification and closure of all biliary communications. Although the literature contains many descriptions of laparoscopic treatment of echinococcal cysts, the serious consequences of spilling parasitic debris and the complexity of the biliary fistulas make it difficult to recommend the laparoscopic approach for echinococcal cystic disease.

Perhaps the most important indication for laparoscopic liver surgery in the pediatric population is for evaluation and biopsy of the liver in cases of intra-abdominal malignancy. Despite excellent preoperative evaluation with CT, MRI and transcutaneous ultrasound, liver lesions may not be detected before laparotomy. Laparoscopic evaluation of the liver combined with laparoscopic ultrasound can extensively evaluate the liver for lesions and help guide necessary biopsies. This has been extremely useful in adult patients for evaluation of colorectal metastasis to determine feasibility of liver resection and in detecting pancreatic cancer metastasis to select patients appropriate for resection. When unresectable lesions are identified the laparoscopic evaluation may save the patient a laparotomy. In children, laparoscopic exploration and identification of liver disease may provide an indication for preoperative chemotherapy. The laparoscopic approach to liver biopsy may also be helpful in cases when multiple liver biopsies are needed or when liver biopsies are needed in conjunction with other staging procedures such as lymph node biopsy or primary tumor biopsy.

The indications for removal of malignant primary liver tumors by the laparoscopic approach are unclear at this point. Many centers with extensive experience in laparoscopic liver surgery consider malignant primary liver tumors a contraindication to the laparoscopic approach.

The location of the lesion within the liver is the most important variable in determining whether a lesion is resectable via the laparoscopic approach. The size of the lesion is not as important. The "safe" anterolateral segments (Couinaud classification) include segments II, III, and the inferior portion of segment IV of the left lobe, and segments V and VI in the right lobe. These are anterior and lateral and thus accessible laparoscopically. Upper and posterior segments are not easily visualized, and lesions located in these segments should not be approached laparoscopically. These lesions, however, may be biopsied via a transdiaphragmatic thoracoscopic approach.

These are a few situations that contraindicate the laparoscopic approach to liver surgery. As already discussed, Echinococcal cysts, primary liver malignancies, and polycystic liver disease are probably best handled with an open approach. Excision of a mass located near a major vessel may be difficult because of the difficulty controlling any major bleeding laparoscopically. There is also the concern for potential carbon dioxide embolism through major veins (see discussion below). Masses located in posterior or central positions of the liver may not be accessible via the laparoscopic approach. As in open liver surgery, bleeding may be difficult to control

in patients with cirrhosis or coagulopathy, and these conditions are considered contraindications to the laparoscopic approach at most institutions. However some of the newer modalities of lesion destruction using cryotherapy or radio-frequency ablation may be quite appropriate for patients with cirrhosis, especially when performed by the laparoscopic approach.

Anesthesia

The preoperative evaluation of patients evaluated for laparoscopic liver surgery is similar to that of any preoperative liver patient and include evaluation of liver function, especially coagulation status. Blood specimens should be obtained for type and cross-match should transfusion be required. The patient should have adequate intravenous access for fluid and blood product administration and possibly for central venous monitoring. Arterial monitoring is indicated when resection is planned. Urinary bladder catheter drainage and nasogastric drainage are used routinely. Care should be taken to maintain the patient's temperature with warmed intravenous fluids, warming blankets and a warming circuit on the ventilator to prevent systemic hypothermia. This is especially important during cryoblation (see below).

When pneumoperitoneum is used during laparoscopic liver surgery, at 12-14 mm Hg pressure, there is a theoretical risk of CO₂ embolism particularly during division of the parenchyma when venotomies may be made that can allow the CO₂ gas access to the venous system. It is necessary to constantly monitor the patient's hemodynamic status and end tidal CO₂ during the operation. Despite these risks, most centers perform laparoscopic liver surgery using pneumoperitoneum with no adverse effects. Some centers have developed "gasless" laparoscopic methods of exposure using devices that lift the abdominal wall.

OR Set Up

It is most important in setting up the operating room to keep in mind the potential need to convert to an open procedure. Instrumentation for laparotomy should be immediately available, and the patient and family should be aware of the possibility of laparotomy.

The patient is positioned prone at the foot of the operating room bed. Care is taken to adequately pad the patient. The arms should be abducted to allow access to the upper abdomen and in young children and infants extended above the head. The position of the legs depends on the patient's size. In infants the feet can remain on the OR table. In small children the legs can be bent at the knee and padded and draped off the end of the table. Older children are placed in low stirrups within minimal flexion at the hips. The primary surgeon stands at the foot of the bed or between the legs and the second surgeon at the patient's left side. An additional assistant or computerized robotic camera drives and mechanical retractors can be positioned at the patient's right side, and the scrub nurse is between the first and second surgeon. Monitors are placed at the patient's shoulders. When available, split image monitors allowing picture-in-picture capability are useful to simultaneously display laparoscopic and ultrasound images. When not available, one monitor is used for each image.

The reverse Trendelenburg position is helpful for anteriorly and superiorly located lesions and helps keep the intestines in the lower abdomen. For right-lateral

lesions, the patient is rotated into the semilateral right side up position to provide the best exposure.

Techniques

The basic sequence of the laparoscopic liver procedures is identical to the step by step components of open liver surgery: exploration, mobilization of the liver, determination of resectability, control of vascular and biliary structures, parenchymal dissection, hemostasis, identification and control of bile leak, and specimen extraction.

Port Placement

The telescope is placed through an umbilical port and connected to a 3-chip video-laparoscope. The 5 mm telescope provides excellent visualization. Angled lenses, usually 30° scopes, allow the anterior and lateral surfaces to be examined more easily than with 0° scopes. A subxiphoid port for a suction-irrigator (which can also be used as a probe and for retraction in younger children) or for a fan retractor in larger children is very useful. A 5 mm port placed in the right mid-axillary line is used for a laparoscopic Pringle maneuver. This posterolateral position keeps the instrument in the back of the operative field and avoids interfering with the anterior working instruments. Working port positions depend on the location of the lesion within the liver and the specific procedure to be performed. Positions also depend on the size of the child or infant. In smaller patients the ports are placed lower in the abdomen so that instruments will be able to reach the surgical site without hitting each other. For procedures not requiring laparoscopic ultrasound and division of large amounts of liver parenchyma, 3 mm and 5 mm ports suffice. For situations in which use of laparoscopic ultrasound probes, ultrasound dissector-aspirators and Argon beam cautery is anticipated, 10 mm ports will be required. Linear stapling devices require 12 mm ports.

Pneumoperitoneum is established by insufflating the abdominal cavity with CO₂. The intraabdominal pressures should be limited to 12 mm to 14 mm Hg, and alarmed monitors should be used continually to assess the pressures.

Evaluation

Despite the excellent quality of CT and MR images of the liver, a significant fraction of patients thought to have resectable tumors based upon these studies are later found unresectable when evaluated with laparoscopy and laparoscopic liver ultrasound. In many centers laparoscopy with ultrasound is done routinely before any open liver procedure to save unresectable patients a laparotomy. Angled scopes allow visualization of the surface of the liver, and because of the magnification obtained, lesions only a few millimeters in diameter are easily detected. The liver can be further mobilized (see below) as necessary to gain access to areas not immediately accessible to the scope.

Laparoscopic Ultrasound

Use of laparoscopic ultrasound further improves evaluation of liver lesions. Various probes are available, the most recent being flexible and more maneuverable. Most have several modes including B-mode, M-mode and color-flow Doppler capability, the latter useful for distinguishing biliary structures from blood vessels. A

9.6 mm variable Hz probe is available from Bruel & Kjaer Medical Systems, Marlborough, MA. This is placed through a 10 mm port placed at the mid-clavicular or anterior axillary line on the right side. For evaluation or left-sided lesions, the port may be placed in the left mid-clavicular line. A disposable cannula with a rubber valve is used to avoid damage to the transducer surface from metal valves on the reusable ports. At times it may be necessary to divide adhesions to gain full access to the liver, and additional 3-5 mm ports may be needed to accommodate endoscopic forceps and scissors or cautery devices.

Contact between the transducer and the surface of the liver is important to achieve and optimal acoustic window. Saline (10 cc) can be placed into the probe's tip cover and secured with a tie, and the pneumoperitoneum can be partially desufflated to improve contact with the liver surface. Scanning is done systematically beginning at the suprahepatic vena cava and following each of the hepatic veins into the liver. Similarly, the portal vein is identified and followed to its peripheral branches. The vena cava is also thoroughly evaluated. A lesion encroaching on any of these structures would make the lesion unresectable by the laparoscopic approach and possibly by the open approach as well.

Mobilization of the Liver

For visual inspection, ultrasound evaluation and simple needle or wedge biopsies it may be necessary to expose the superior, inferior and lateral surfaces of the liver. Much of this can be done with simple retraction maneuvers that do not require division of any of the supporting ligaments. A suction-irrigator placed through a 5 mm upper midline abdominal port is used to elevate the left or right lobes during laparoscopic inspection and ultrasound evaluation. To expose the porta hepatis and the bile ducts, a port in the right anterior axillary line allows the fundus of the gallbladder to be grasped and elevated superiorly and anteriorly. The falciform ligament can also be grasped to move the liver from side-to-side to obtain better later exposure.

Division of the falciform and inferior retraction of the liver provides access to the anterior/superior aspects of the liver. This maneuver becomes necessary in preparation for segmentectomy and lobectomy when control of the hepatic veins as they enter the cava is desired. The ligamentum teres and falciform ligament are divided followed by the right or left (corresponding to side of the lesion) triangular ligaments. This can be done with the harmonic scalpel (UltraCision, Ethicon EndoSurgery), the Ligasure (ValleyLab) or with electrocautery. The liver is then retracted inferiorly using a fan retractor in the subxipoid port. The 30° scope is valuable here.

Retraction of the gallbladder anteriorly and superiorly provides exposure of the porta to allow dissection of the porta structures. The cystic duct is followed to the common bile duct which is then dissected proximally to the porta. Control of the hepatic artery, portal branches and biliary radicals can be achieved with this exposure as necessary depending on the planned resection. This exposure is also necessary in order to perform the Pringle maneuver preparations. In cases when parenchymal division is anticipated or a possibility, having a clamp available for control of hepatic inflow is advisable. A noncrushing endoscopic bowel clamp is introduced through a right lateral port and is used for up to one hour, preferably at short intervals.

Needle Biopsy

Core biopsies can be obtained using a Tru-cut needle (Travenol Division, Valencia, CA) placed percutaneously through a tiny stab incision. Laparoscopic and ultrasound guidance allows accurate biopsy of any identified lesions. When ultrasound is used to guide biopsy, the probe and needle should be kept in parallel to best monitor placement of the needle tip within the lesion. Bleeding at the biopsy site can be carefully monitored after removal of the needle and can be controlled with electrocautery or thrombin-soaked gelfoam.

Wedge Excision

Small peripheral lesions located close to the liver edge in segments III, IV, V and VI can be wedge resected without the need for liver mobilization. Various methods are available to divide the parenchyma at the liver edge. As in open surgery, sutures can be placed on either side of the lesion to compress the parenchyma and control bleeding. The sutures are passed into the abdomen either through the cannulae or directly through the abdominal wall depending on patient and needle size. Harmonic scissors (Ethicon Endosurgery), Ligasure (ValleyLab), electrocautery or endo-linear staplers can be used to divide the tissue and resect the lesion within the wedge of liver. When using electrocautery, wider margins are necessary because of the desiccating effect that may interfere with evaluation of the lesion. Inspection for bleeding and bile leaks from the cut edge is then performed as described below.

Cyst Fenestration

Simple cysts located anteriorly and superficially within the liver are treated with fenestration. Four ports are used. A 5-10 mm port at the umbilicus houses the 0 or 30° scope. Through a 5 mm subxiphoid port a probe or suction-irrigator wand is placed to expose the liver. The two working ports are in the right and left lateral abdomen. The dome of the cyst is punctured with scissors, and the cyst contents are aspirated. The wall of the cyst is examined for any indications of neoplastic changes such as septations or irregularities. The anterior cyst wall is then excised using electrocautery, harmonic scissors or Ligasure to within 2 or 3 mm of the liver edge, carefully achieving hemostasis and checking for any evidence of bile leak. Any identified leak can be clipped or tied as necessary.

Laparoscopic management of hydatid cysts has been described but as its indications are controversial. All patients are given perioperative albendazole to help prevent recurrence of Echinococcal disease in case of spillage of hydatid debris. First, cholecystectomy is performed, and a cholangiography catheter is placed in the cystic duct for cholangiography to identify any parasitic debris in the common duct and possible intrahepatic biliary fistulae. The cyst is sterilized by percutaneous instillation of 10 to 20 cc of hypertonic saline for 10 minutes. The sterilized debris is then aspirated with care taken to prevent spillage of material. After evacuation, the area is isolated with hypertonic saline-soaked gauzed (which is tagged with suture for easy removal) and the cyst is opened. Methylene blue injected through the transcystic duct catheter can demonstrate any biliary leaks that can be sutured laparoscopically. The residual cavity is then filled with omentum. Alternatively, pericystectomy without cyst aspiration can be done for small partially calcified anteriorly located hydatid cysts.

Methods to Divide Parenchyma

Division of the liver parenchyma begins with scoring Glisson's capsule approximately 2 cm from the lesion using electrocautery or Nd:YAG laser (40-60 watts). A "four hand technique" with two surgeons working simultaneously has been described to allow excellent visualization and safe and efficient division of the parenchyma. The first surgeon is responsible for retraction and division of the parenchyma. Generally an atraumatic grasper is used in the left hand for retraction and exposure, and the laparoscopic ultrasonic dissector (CUSA, Valley Lab Inc, Boulder CO) is used in the right hand. Alternatively, the parenchyma can be gently fractured using the tip of a clamp. The second surgeon is responsible for keeping the field clear of debris and blood using the suction-irrigator in the left hand. All vessels and ducts exposed by the first surgeon's dissection are clipped using an endoscopic multiply-loaded clip applier that is kept near the area of dissection in the second surgeon's right hand. This four-hand technique allows the parenchymal dissection to proceed efficiently and minimizes blood loss and risk of CO₂ embolus. Other hemostatic tools such as electrocautery, LCS (Ethicon Endo Sugery), Legasure (Valley Lab) and the Argon beam coagulator are used as needed by the second surgeon (in the left hand) to seal vessels and the raw liver surface. When larger vascular structures are identified they can be controlled and divided with endoscopic linear staplers fit with vascular (staple length 2 mm) cartridges. Maintaining temporary positive end-expiratory pressure during division of large hepatic veins may help avoid CO₂ embolus.

Left Lateral Segmentectomy

As described above, the ligamentum teres, falciform and left triangular ligaments are divided. The inferior vena cava is identified at the diaphragm using a fan retractor in the subxiphoid position to displace the liver inferiorly. Next, expose the left hepatic vein at its entrance to the cava using a peanut and right angle clamp dissection. Ligate the vessel with a heavy silk tie, but do not yet divide the vein. Sometimes the extrahepatic portion of the vein may be too short to control and this step is impossible. Pringle maneuver preparations are made, and a bowel clamp is placed. To prepare for division of the parenchyma the capsule is scored 1 cm to the left of the falciform ligament, and the four-hand technique is used to fracture the liver. The vasculobiliary pedicles of segments II and III are identified and divided between clips. An endoscopic linear stapler is used to intraparenchymally divide the already tied left hepatic vein. The specimen is placed within an endocatch sac (Ethicon) and removed through and expanded umbilical port.

Right Hepatectomy

Right side anatomic resection has been described as a laparoscopically-assisted procedure. The mobilization of the liver and isolation of the biliary and vascular structures are performed laparoscopically as previously described. The ligamentum teres, falciform, right triangular and coronary ligaments are divided and the right liver is mobilized from the diaphragm. The liver is again retracted downward to expose the suprahepatic vena cava. Gentle dissection with a peanut is done to obtain control of the extrahepatic right hepatic vein. Control of the right hepatic artery and right bile duct at the porta are achieved by dissecting at the triangle of Calot and following the common hepatic duct and right hepatic artery to the porta. Vessel

loops are used to isolate the biliary and vascular structures until division, using clips for the bile duct and artery and the endoscopic linear stapler fit with the vascular cartridge for the right branch of the portal vein. The laparoscopic portion of the procedure is now completed. A midline upper abdominal incision is then made and the anterior abdominal wall lifted with a Mouret retractor for gasless laparoscopic surgery. The parenchyma is divided using the four hand technique without pneumoperitoneum to avoid CO₂ embolus. The specimen is placed within an endocatch sac (Ethicon) and removed through the mini-laparotomy midline incision.

Methods to Control Bleeding

The Argon beam coagulator allows cauterization without contact of the probe at the liver surface. Use of the argon beam risks over-pressurization of the abdominal compartment that may cause hemodynamic collapse and/or argon gas embolisms. It is important to monitor intraabdominal pressure with an alarm system during use of the argon coagulator, and limit argon gas flow to 4 L/min and power output to 100-200 watt. Leaving the valve open on one of the ports to allow gas to leave the abdomen also minimizes any increase in intraabdominal pressure during use of the argon coagulator. After control of larger vessels, fibrin sealant (Tisseel, Baxter, Deerfield, IL) is sprayed on the raw surface of the liver. This may also help prevent bile leak. Thrombin-soaked Gelfoam can be packed into bleeding crevices or lacerations to achieve hemostasis. Surgicel is also a helpful topical hemostatic agent that can be draped over the raw liver surface and has been used with success.

Identification and Control of Bile Leaks

If there is any question of a bile leak, a cholangiogram using methylene blue can identify any open bile ducts at the raw edge of the liver. Control of the leak can be achieved with a suture placed laparoscopically or with endoscopic clips. The magnified view of the laparoscope and modern optics provide excellent visualization, and biloma has not been a common postoperative complication of laparoscopic liver surgery. Drains are used at the surgeon's discretion if any question of a continuing bile leak exists and may be able to prevent biloma and control the bile leak during the postoperative period.

Lesion Destruction

Newer methods to destroy rather than remove liver lesions are gaining in popularity. These methods use extreme heat or cold to locally destroy tumor cells. Typically these techniques are used when the lesion is not amenable to surgical resection because of location, multiple lesions or because of low hepatic reserve limiting surgical resection. These techniques have been particularly useful for metastatic disease (colon, neuroendocrine) and hepatocellular carcinoma in adults. Long term followup is not yet available, but most reports suggest that it may be equivalent to resection. The indications for and application of this technology in the pediatric population are not yet described.

Cryoablation

Extreme cold using liquid nitrogen freezes and destroys the tumor cells. Laparoscopic cryoprobes (CryoMedical Sciences, Rockville, MD) are available in a variety of sizes. The probes deliver the liquid nitrogen to the tumor creating a frozen

zone called "ice ball," and the probes also simultaneously monitor tissue temperature. The size of the cryoprobe determines the diameter of the "ice ball" and the area of the tissue that is destroyed. The 3 mm probe creates a 1 cm ice ball, the 4.8 mm probe creates a 5 mm ice ball, and the 8-mm probe creates a 6 cm ice ball. For most laparoscopic procedures the 4.8 mm probe is used. The probes are placed through conventional laparoscopic ports.

Laparoscopic ultrasound is used to locate and assess the characteristics of the lesion to be ablated. The liver is mobilized as necessary to obtain the most direct access to the lesion and avoid traversing any major biliary structures or blood vessels. The port for the cryoprobe is placed so that the probe can directly enter the liver at the location of the lesion. The capsule of the liver overlying the lesion is scored using electrocautery, and the probe is inserted through the capsule and into the lesion. Ultrasonic guidance is used to position the tip of the cryoprobe at the deep margin of the tumor keeping the cryoprobe and ultrasound probe in parallel. Freezing is then begun continuously monitoring tissue temperature and development of the ice ball with ultrasound. Freezing is continued until the ice ball exceeds the tumor edge by 1 cm and the tissue temperature reaches -190°C . Nearby vascular structures with high blood flow rates may act as cold sinks and prevent adequate freezing in that area. After complete freezing, the ice ball is allowed to thaw, monitoring the thaw process with ultrasound. A second freeze-thaw cycle can be performed. When tissue temperature reaches -20°C the cryoprobe can be removed. It is necessary to carefully inspect the liver for bleeding and bile leak at the probe site.

Radiofrequency Ablation

Radiofrequency waves are used to generate heat within a lesion to destroy the tumor via protein denaturation. It can be done for single as well as multiple lesions as long as the liver volume destroyed is less than 40% total liver volume and the patient has adequate hepatic reserve. Radiofrequency ablation was initially introduced as an open procedure but has now been extended to percutaneous placement of the ablation electrodes under laparoscopic visual and ultrasound guidance. There may be advantages to the laparoscopic approach over the open in that positive pressure pneumoperitoneum may reduce hepatic blood flow and therefore reduce heat loss in lesions located near larger vessels (the heat sink effect). Additionally, to minimize heat sink, a laparoscopic Pringle maneuver can be performed for temporary occlusion of hepatic inflow during heating. The Zomed Model 500 RF generator (460 kHz) is used with model 3.1 35 cm RITA electrosurgical probes (Zomed International, Mountain View, CA, USA) that are placed percutaneously and guided by laparoscopic visualization. The mother probe is the primary electrode and is inserted into the tumor using laparoscopic ultrasound control. There are four secondary electrode housed within the mother probe that are extruded once the mother probe has been positioned within the lesion. Each of the secondary electrodes has a thermocouple mounted at its tip. The position of the secondary electrodes inside the tumor can be verified by ultrasound before ablation. It is important that the secondary electrodes tips do not breach Glisson's capsule. Optimal position of the secondary electrodes causes ablation of a zone that extends 0.5 cm beyond the limits of the tumor. The power is set at 50 watts, and the lesions are heated to a temperature of $>90^{\circ}\text{C}$ for 10 minutes. During and after heating, the ablated zones can be

assessed with ultrasound and appear as hyperechoic lesions. Tumor nodules less than 2.5 cm generally can be ablated with a single insertion of the mother probe, and larger lesions can be treated with multiple overlapping ablation fields.

Conclusions

Laparoscopic liver surgery, both novice and advanced techniques, can be applied to pediatric patients. Procedures such as and lobectomy require both advanced laparoscopic skill as well as significant experience with open liver surgery and currently are performed at only a few centers. Many other procedures such as biopsy, ultrasound evaluation, fenestration of cysts, and excision of peripheral lesions will be more widely employed.

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The Use of Minimally Invasive Surgery for Conditions of the Pancreas in Children and Infants

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Introduction

As the techniques in minimally invasive surgery, as well as the instrumentation involved, improve, these techniques are being applied to essentially any operative procedure which may be indicated in children and infants. While pancreatic conditions requiring surgery in children are relatively rare, minimally invasive surgical techniques can also be applied to these conditions. Conditions affecting pediatric patients involving the pancreas include persistent hyperinsulinemic hypoglycemia of the newborn (PHHN), islet cell tumors of the pancreas, post traumatic pancreatic pseudocysts, as well as others. Laparoscopic surgery may also be used as a diagnostic tool in conditions involving the pancreas.

Despite widespread use of MRI and CT scans, there is frequently some ambiguity regarding the exact location and histology of a lesion within the pancreas. Laparoscopic exploration of the lesser sac can often be helpful in establishing a definitive diagnosis prior to therapy. The use of laparoscopic ultrasound, which has just emerged in the pediatric surgical field, should be considered as an adjunctive diagnostic tool to minimally invasive surgery for these children. As with other rare conditions, the use of minimally invasive surgery is essentially limited only by the skills of the surgeon, and consideration to minimally invasive techniques should be given prior to open operative intervention.

Technical Issues

The use of minimally invasive surgery for pancreatic operations in children requires advanced minimally invasive surgical skills. The best approach to the pancreas we have found is to place a 3 mm or 5 mm cannula at the umbilicus, through which a 0° or 30° laparoscope is introduced. This provides a panoramic view of the abdomen. Following this, two or three additional cannulae are introduced. A 3 mm cannula is placed in the right upper quadrant, through which 3 mm graspers or dissectors can be used, and a 5 mm cannula is placed in the left upper quadrant. The larger cannula allows introduction of the 5 mm harmonic scalpel, which can be invaluable in dividing vascular structures.

After cannulae insertion, the patient is placed in reverse Trendelenburg position to allow displacement of the intestines inferiorly by gravity. An orogastric tube or nasogastric tube should be inserted into the stomach, to allow decompression. We

have found that transabdominal fixation sutures are helpful in elevating the stomach up to the anterior abdominal wall. Two or three transabdominal fixation sutures are placed, providing excellent visualization of the pancreas and the lesser sac. After elevation of the stomach, the left-hand 3 mm grasper and the right-hand 5 mm harmonic scalpel are used to divide the gastrocolic ligament throughout the length of the greater curve of the stomach. Care is taken to avoid injuring the gastroepiploic blood vessels. Following division of the gastrocolic ligament, entry into the lesser sac can be achieved.

Use of the laparoscope offers several potential advantages. First, this is clearly a less invasive means of gaining exposure to the pancreas, particularly compared with the traditional approach using a large transverse abdominal or chevron-type incisions. Also, laparoscopic surgery provides magnification and focused illumination of the operative field, which is important with pancreatic surgery, especially in newborns. We have also found that use of the AESOP® robotic arm (Computer Motion, Santa Barbara, CA) is optimal in these operations by providing stable control over the camera during these somewhat lengthy operations. AESOP®'s very precise movements provide a safer, more reliable technique of camera manipulation. The majority of operations, required on the pediatric patient with a pancreatic problem, could be initiated using the technique described above. Depending on the indication for the operation, additional cannulae may be required.

As with most minimally invasive surgery, minimally invasive surgery on the pancreas has been much more frequently described in the adults. Splenic-preserving distal pancreatectomy for tumors, especially islet cell tumors, is now performed fairly commonly. Also, laparoscopic distal 70% pancreatectomy as well as splenectomy have been described for the treatment of chronic pancreatitis. Staging laparoscopy to evaluate the resectability as well as to intraoperatively stage pancreatic malignancy is also commonly performed in adults, often using laparoscopic ultrasound. Laparoscopic pancreaticoduodenectomy has been recently described both in the animal model as well as clinical practice.

Specific Techniques

Laparoscopic Pancreatectomy in Infants with Persistent Hyperinsulinemic Hypoglycemia of the Newborn (PHHN)

The operation for this condition is performed after medical stabilization. These infants have very severe hypoglycemia from birth and require very careful medical management with streptozotocin, glucagon, as well as intravenous dextrose to prevent the major neurologic sequelae that can result from this condition. Once the infant is stabilized, they are transported to the operating room, general anesthesia induced, and the abdomen prepped and draped in the usual fashion.

Access to the peritoneum is gained by the previously described technique using a 5 mm cannula at the umbilicus, 5 mm cannula in the left upper quadrant and a 3 mm cannula in the right upper quadrant (Fig. 21.1). Following establishment of access to the peritoneal cavity, the stomach is transfixed to the anterior abdominal wall, achieving visualization of the lesser sac. The distal pancreas is then dissected carefully, using fine Maryland dissectors, from the retroperitoneum and splenic vessels.



Figure 21.1. Infant with PHHN after 75% distal pancreatectomy showing cannulae placement. An additional right upper quadrant 3 mm cannula was placed for a liver retractor.

The multiple short venous branches from the splenic vein to the pancreas should be divided using the 5 mm harmonic scalpel or bipolar electrocautery. These veins are very small in the newborn and are easily coagulated by either technique. Dissection of the pancreas from the underlying structures is continued in this manner to the level of the superior mesenteric artery and vein. The surgeon must decide at this point whether to stop the resection at this level, which is a less technically demanding operation, or continue the dissection more proximally and perform a 90% pancreatectomy. The 90% pancreatectomy provides better definitive therapy, however is a much more technically difficult procedure.

After dissection of the pancreas to the desired level of resection, a single 3.0 Vicryl suture is passed into the abdomen. This is then placed around the pancreas and tied, using either intracorporeal or extracorporeal suturing technique. One or two sutures can be placed, and in the newborn pancreas, this provides adequate closure of the pancreatic stump. Alternatively, the pancreas transection can be performed with an endoscopic stapling device, although this requires a much larger cannula size (12-15 mm) currently. The resected pancreas is then removed via the 5 mm cannula, thus completing the pancreatectomy. No drains are placed, the pneumoperitoneum is released and the 5 mm umbilical cannula site is closed. The 3 mm and left upper quadrant 5 mm cannula sites are closed using a single skin suture. The patient is then returned to the post anesthesia recovery unit.

At Le Bonheur Children's Medical Center (Memphis, TN) we performed a laparoscopic 75 % pancreatectomy in a patient with PHHN. The patient tolerated an age appropriate diet later the same day. Despite a technically successful operation, the patient had residual symptoms and required a 95% pancreatectomy. This operation was elected to be performed in an open fashion.

It is currently controversial whether to perform a 75% or 95% pancreatectomy in children with PHHN. Laparoscopic surgical techniques offer a very non-invasive method of performing a 75% pancreatectomy, which is not technically demanding. More extensive pancreatectomy can also be done in this manner, however it becomes much more difficult. The technique of minimally invasive 75% pancreatectomy is ideal when it provides definitive therapy. In the event that the patient has recurrent symptoms and requires additional operative therapy, this technique should provide less scarring in the pancreatic bed, allowing reoperative surgery to be done more easily.

Internal Drainage of Pancreatic Pseudocysts

The most common cause of pancreatic pseudocysts in children is blunt abdominal trauma. A large number of such lesions will resolve spontaneously. An additional number will require percutaneous drainage and will resolve. However, a minority will require operative intervention. This has traditionally involved exploratory laparotomy with internal drainage. This could be provided by cyst gastrostomy, cyst duodenostomy, or a cyst jejunostomy. Preoperative CT scan should be obtained to determine whether the laparoscopic approach might offer benefit to these patients.

A large, anterior, pseudocyst that abuts the stomach is amenable to minimally invasive surgery. Exposure to the pancreas is achieved as described above. Access to the lesser sac is accomplished using the harmonic scalpel to divide the gastrocolic ligament. This allows laparoscopic visualization of the lesser sac and the pancreas with the cyst. To assist with the surgery, a flexible pediatric gastroscope can also be advanced into the stomach. This provides additional exposure, and the point of maximal displacement of the posterior gastric wall by the pseudocyst can be determined.

After visualization of the precise location of the pseudocyst, both from the abdomen as well as via the gastroscope, a small anterior gastrotomy can be made in the stomach, providing direct access to the pancreatic pseudocyst. The laparoscope is advanced through the gastrotomy and a posterior gastrotomy is made directly in continuity with the posteriorly located pseudocyst. A small posterior gastrotomy is made initially and then enlarged with an endoscopic stapling device. This also provides a hemostatic anastomosis between the stomach and the pseudocyst. The anterior

gastrotomy can then be closed either with suturing techniques or by the endoscopic stapling device.

Cyst jejunostomy can also be performed using minimally invasive techniques. Entry into the abdomen is performed as previously described. A loop of jejunum is then elevated next to the pancreatic pseudocyst and, using intracorporeal and extracorporeal suture techniques, affixed to the pancreatic pseudocyst with 3.0 silk sutures on ski needles. An enterotomy is then performed as well as a small opening into the cyst and a laparoscopic GI stapling device is used to establish an anastomosis between these two structures. Cyst duodenostomy is probably best reserved for open surgical procedure, as this is a very difficult area and carries with it increased risk due to the entry of the bile duct into the second portion of the duodenum.

Minimally invasive surgical techniques could also be used to perform a distal pancreatectomy if the pseudocyst is isolated to the tail of the pancreas. The technique of pancreatectomy would be similar to that described above for hyperinsulinemic hypoglycemia of the newborn.

Enucleation of Islet Cell Tumors

Although rare in children, islet cell tumors of the pancreas do occur and may be approached laparoscopically both for diagnosis as well as definitive therapy. This is an ideal use of laparoscopic ultrasound, as preoperative imaging studies are notoriously inaccurate regarding this diagnosis. Exposure to the pancreas is as described above, with transabdominal fixational sutures placed into the stomach to allow elevation off of the pancreas, allowing good visualization of the lesser sac. Some authors recommend that for resection or enucleation of islet cell tumors the patient be rotated laterally 45° with the left side up and placing the patient in reverse Trendelenburg position. This enhances the anterior view of the tail of the pancreas.

Following this, the inferior aspect of the pancreas is dissected from the retroperitoneal fat, with either hook cautery or the 5 mm harmonic scalpel until the pancreas is mobile and the splenic vein is seen posteriorly and superiorly. The tail of the pancreas is then grasped and elevated anteriorly and inferiorly to expose transverse branches of the splenic artery and vein. These branches, as mentioned previously, can either be cauterized with bipolar electrocautery or, preferably, the 5 mm harmonic scalpel. Once the islet cell tumor has been localized, the dissection can be performed using either hook cautery or fine Maryland dissectors. The feeding pancreatic vessels to the tumor can be coagulated using harmonic scalpel or bipolar electric cautery. A drain can be left in the lesser sac following enucleation from the pancreatic parenchyma. Due to the more common nature of this tumor in adults, as well as more advanced minimally invasive surgery being performed in adults, reports of this operation are thus far limited to the adult population.

Summary

In conclusion, while pancreatic disorders requiring surgery are relatively rare among children and infants, these conditions can be expected to be seen in the busy pediatric surgical practice. When operative intervention is indicated, minimally invasive surgical techniques may offer advantages to the patient in both diagnosis and therapy of these conditions.

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Pediatric Laparoscopic Adrenalectomy

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Introduction

The potential advantages of laparoscopic adrenalectomy in children are cosmetic, decreased postoperative pain, and quicker hospital discharge compared to the open approach. There are, however, several disadvantages that must be considered prior to attempting this operation. Many adrenal tumors in children are malignant, invasive, and require radical resections and lymph node dissection or sampling which can be difficult and potentially dangerous to attempt laparoscopically, especially if aortocaval nodes are involved. This is not a contraindication but it does add to the technical difficulty of the operation. There is a theoretical risk of port site metastases, a high incidence of bilaterality (e.g., 25-50%) for childhood pheochromocytomas, and the potential for seeding of the peritoneal cavity especially if the tumor is broken upon removal.

Patient Selection

Selecting the appropriate pediatric patients for laparoscopic adrenalectomy is difficult. The indications are not as numerous as they are for the adult population. Those tumors that are most amenable to laparoscopic resection are small tumors, which are well encapsulated and therefore are not invasive or infiltrative. It is also important to choose tumors that are firm and not likely to break easily with manipulation. The tumors that are usually well-encapsulated and not likely to break include pheochromocytomas, cortical adenomas, ganglioneuromas, and many types of stromal tumors such as neurofibromas, fibromas, and lipomas. Unfortunately, neuroblastomas (the most common adrenal tumor in children) are not usually amenable to laparoscopic resection because they are not well encapsulated and tend to be highly infiltrative. Similarly, adrenocortical carcinomas tend to be friable and can easily break apart upon manipulation running the risk of seeding the peritoneal cavity.

Anesthetic Considerations

There are few anesthetic considerations for children undergoing adrenalectomy. Standard endotracheal intubation is performed and the child is given an inhaled and/or intravenous anesthetic agent, an opiate, and a paralytic agent. Nitrous oxide is not used. If a pheochromocytoma is to be resected, anesthetic agents which are vagolytic and/or sensitize the myocardium to the arrhythmogenic effects of catecholamines (i.e., pancuronium, halothane) are best avoided. Bilateral adrenalectomy requires corticosteroid replacement.

The procedure is most commonly performed with the child in the lateral decubitus position so all bony prominences and the axilla need to be cushioned. A bean

bag that molds with suction is commonly used to stabilize the patient, obviating the need for tape or straps.

Techniques for Laparoscopic Adrenalectomy

An orogastric tube is placed and removed at the end of the procedure. Neither intravenous antibiotics nor a urinary drainage tube are used. There are two approaches to adrenalectomy, the lateral transperitoneal and the retroperitoneal (lateral or posterior). Each has its merits and disadvantages, as described below. The most experience has been achieved with the lateral transperitoneal approach and this should take approximately 1.5 to 2.5 hours to complete. The differences between a right and left adrenalectomy will be highlighted below using the lateral transperitoneal approach.

Transperitoneal

This is the most common laparoscopic approach for adrenalectomy. The patient is placed in the full lateral decubitus position. This allows the viscera to “fall away” with gravity, thus minimizing their manipulation. The anatomical landmarks are easily recognized and there is ample working space making removal of large (>6 cm) tumors possible. It may be difficult if there are adhesions from prior surgery.

Retroperitoneal

The patient is placed either prone (posterior approach, good for bilateral tumors) or lateral decubitus position. A balloon dissector inserted just caudad to the tip of the 12th rib is used to create the retroperitoneal space. It is often impractical to use the retroperitoneal approach in a relatively small child due to the paucity of space and the need for adequate visualization and manipulation of instruments. The landmarks are often obscure and it is difficult to remove large tumors. For these reasons, this is the least common approach used for pediatric laparoscopic adrenalectomy.

Laparoscopic Right Adrenalectomy

This is performed in the left lateral decubitus position with the kidney rest raised and the table maximally flexed to create the largest possible distance between the costal margin and the iliac crest. Four trocars are inserted two fingerbreaths below the costal margin from the midclavicular line to the posterior axillary line. Two trocars are 5 mm in size (camera, fan retractor, clip applicator) and two are 3 mm in size (working instruments). One must have a second, 3 mm or less sized camera in order to use the second 5 mm port for the clip applicator. If this is not available then three trocars are 5 mm and one 3 mm. The Veress needle technique is used to establish a pneumoperitoneum to a pressure of 12-15 torr. A fan retractor is inserted in the most medial port to retract the right lobe of the liver, a 5 mm 30° telescope is used through the second port and the two lateral ports are the working ports. The monopolar L-hook cautery, ultrasonic dissector, or scissors with cautery (monopolar or bipolar) is used for almost all of the dissection. The dissection is begun by dividing the right triangular ligament, allowing the right lobe of the liver to be retracted superiorly, thus exposing the adrenal gland. Circumferential dissection of the gland is then performed. The key step in the dissection is the ligation of the short adrenal vein, which drains directly into the inferior vena cava. If it is visible after elevation of the liver and upon entering the retroperitoneum it can be ligated early in the course

of the operation. More commonly, however, partial mobilization of the superior pole needs to be performed before adequate exposure of the adrenal vein can be obtained. After identification, a right-angled dissector is used to help gain vein length in order to facilitate the placement of two staples proximally and one distally prior to division. Occasionally, there are other large veins that need to be divided between clips. The remainder of the gland is mobilized by circumferential dissection. Extraction of the gland can be performed in a variety of ways. The specimen is placed in a heavy nylon bag (Wilson-Cook, Bloomington, IN) and either morsellated and removed piecemeal, or it can be removed intact by enlarging one incision or connecting two incisions. Morsellation of the tumors is often acceptable since an intact capsule is not necessary to differentiate malignant from benign adrenal tumors. The fascia is closed in all trocar sites with a simple interrupted suture.

Laparoscopic Left Adrenalectomy

Patient positioning and port placement are similar to that described for right adrenalectomy. However, often only three ports are needed since gravity helps displace the spleen medially, thus the fan retractor is not needed. The first step is to expose the adrenal gland. In doing this the spleen, pancreas, and sometimes the splenic flexure of the colon must be freed from their retroperitoneal attachments. Using the cautery or the ultrasonic dissector, the lateral splenic attachments are mobilized up to the superior short gastric vessels. This allows the spleen to fall forward, exposing the adrenal gland. Unlike the right adrenal gland, it may be difficult to locate the left adrenal gland, especially if there is a lot of retroperitoneal fat in a large adolescent. If this occurs, laparoscopic ultrasonography using a 7.5 megahertz 10 mm transducer (Aloca, Wallingford, Conn.) can delineate the anatomy. The dissection is similar to that described for a right adrenalectomy.

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Pediatric Laparoscopic Renal Surgery

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History of Renal Surgery

In order to understand the current advancements in pediatric renal surgery, it is important to understand the origins of renal surgery. Prior to 1869, the description of the hydronephrotic kidney was a postmortem event. In 1869 Gustave Simon performed the first successful nephrectomy which paved the way for renal surgery. During this period renal surgery was confined to removal of the kidney and mortality rates were high. In the late 1800s, conservative renal surgery began to emerge with Trendelenburg performing the first pyeloplasty in 1886; however, the patient died several days later due to a colonic injury. The first successful pyeloplasty was credited to Kuster in 1891 which was performed in a 13 year old boy with a solitary kidney. By the early 1900s, nephrectomy had an 80% cure rate but a 20% mortality rate. Pyeloplasty had a 37% success rate and a 10% mortality rate. Various types of flap pyeloplasties began to emerge in the 1920s because surgeons were reluctant to disrupt the continuity between the renal pelvis and ureter. Many techniques have been described that adhere to this principle. The dismembered pyeloplasty was re-introduced by Anderson and Hynes in 1949 (Trendelenburg's original description in 1886 was a dismembered pyeloplasty). As clinical experience with the dismembered pyeloplasty accumulated, it became clear that disruption of the pelvoureteral junction was not detrimental.

Laparoscopic renal surgery began in the early 1990s with gradual expansion of this technology in the pediatric population. Currently, in tertiary medical centers, pediatric laparoscopic nephrectomies are frequently performed with excellent results. Laparoscopic pyeloplasty is performed infrequently.

Anesthesia

Preoperative laboratory evaluation in a healthy patient requires only a hematocrit with ABO determination. Additional laboratory evaluation is directed by the patient's medical history of significant systemic diseases. Although blood transfusion is seldom required, it may be necessary to convert a laparoscopy to a laparotomy if complications occur. General anesthesia via endotracheal intubation is the preferred method. General mask anesthesia or laryngeal mask anesthesia should be avoided due to considerations regarding airway access in patients placed in the prone or flank positions. Children undergoing mask anesthesia during spontaneous ventilation have a greater risk of hypoxia due to their decreased functional residual capacity. This effect is further exacerbated by the pneumoperitoneum and Trendelenburg position. Controlled ventilation via endotracheal intubation avoids this problem. In

addition, there is an increased risk of aspiration in patients undergoing pneumoperitoneum, and endotracheal intubation affords better airway protection. The length of the surgical procedure can be variable, rendering further advantage to endotracheal intubation. Standard inhalation agents (isoflurane, flurane or halothane) are used and nitrous oxide is avoided to obviate intestinal distention. In young patients, high inspired oxygen concentration is advised to reduce the risk of hypoxemia that may occur due to the decreased functional residual lung capacity as mentioned above. End tidal CO₂ measurement is important since this gas can be absorbed through the peritoneum. A small increase in the respiratory rate of 10 to 20 percent can offset this effect and maintain normocarbica. Other detrimental effects of the pneumoperitoneum include decreased tidal volume which can lead to hypoventilation. Pressure limits may need to be increased in those pediatric ventilators that are pressure cycled and not volume cycled. In addition, positive end pressure ventilation can be used to offset the adverse pulmonary effects of the insufflation on the functional reserve capacity and tidal volume. Two large gauge intravenous angiocatheters are placed in the event that rapid fluid resuscitation becomes necessary. An orogastric tube and foley catheter are placed. Some advocate the use of a rectal tube which may decompress the large bowel of gas. Standard monitoring includes electrocardiography, automated blood pressure measurements, end tidal CO₂ measurements, pulse oximetry, temperature probes and esophageal stethoscopes.

Instrumentation for Laparoscopic Surgery

Instrumentation for open surgery has seen relatively little change over the last several decades. Laparoscopic surgery is equipment intensive. In general terms, laparoscopic renal surgery involves gaining access, visualization, placement of dissection instruments, dissection and hemostasis of target tissues, extraction of specimens, and wound closure.

Access

When the Hasson or open technique is used, the cannula, insufflation machine, CO₂ source and tubing are needed. Cannula systems are disposable or reusable. The size of the cannula is determined by the size of the endoscope lens or instruments being used, with the 5 mm and 10 mm sizes being the most common for renal surgery. Larger cannulas can be downsized with adapters. Nearly all cannulas have an insufflation port, which is controlled by a stopcock. This allows attachment of the cannulas to the insufflation machine via tubing, which contains an inline filter.

For closed renal endoscopy, the Veress needle is used first to obtain intraabdominal access for insufflation. The sharp tipped needle has an inner spring-loaded blunt cannula. The blunt inner cannula retracts as the needle is inserted through the abdominal or retroperitoneal wall. Once the needle enters the abdominal or retroperitoneal cavity, the blunt inner cannula springs forward, shielding the intraabdominal or retroperitoneal contents from the sharp needle tip.

Insufflation / Insufflators

The operating room staff should confirm that an adequate supply of CO₂ is available at the start of the procedure. Current insufflation machines are automated and allow manual settings to regulate intrabdominal pressure and CO₂ flow rates. In addition, most machines monitor the total volume of CO₂ infused. For intraabdominal

and retroperitoneal renal surgery, a maximal pressure setting of 15 mmHg is used. A CO₂ flow rate of 4-6 liters is maintained. This preserves the pneumoperitoneum as the instruments are manipulated.

Endoscopes

The rigid endoscope is a central and delicate piece of equipment. For diagnostic purposes the 2 mm endoscope can be used. For renal surgery the 5 mm or 10 mm rigid endoscope is used. The optical view in the 5 mm and 10 mm endoscopes is superior to the 2 mm endoscope. The distal aspect of the lens is vulnerable to damage by improper handling. Small chips in the lens can degrade the optics. Rigid endoscope lenses are manufactured with varying degrees of angulation (range 0-75 degrees). Off axis endoscopes can be difficult to work with but they have advantages in various situations. In renal laparoscopic surgery, the zero degree lens is preferable.

Forceps, Dissectors, Scissors, and Clips

Forceps, graspers and dissectors come in many different shapes and configurations. Some are straight, curved, or fenestrated. The grasping surface may be diamond jawed, coarse or fine grooved. Some instruments have teeth while other may have a locking mechanism. There are also combinations of many of the above features. Many if not all, can be attached to the cautery unit. There is less variation with the dissecting scissors and the most widely used for renal surgery is a curved scissor, which resembles a miniature Mayo scissors. Currently, 2, 3, and 5 mm instrumentation is available. Some, but not all 2 mm instruments may lack rigidity, making renal dissection and retraction more difficult. The 3 mm instruments may avoid this problem while maintaining a smaller entry site and profile. Automatic endoscopic clip applicators are available in 5 and 10 mm sizes. Each device can be used to apply 15-20 titanium clips before another applicator is needed. These are disposable instruments and are easy to handle. The jaws of the applicator should extend beyond the structure to clip and one smooth squeeze of the trigger mechanism is necessary to deploy and coapt the clip. Releasing the grip then reloads the applicator. These devices are ideal for clipping the vessels during renal dissection.

Irrigation/Aspiration

Current irrigation/aspirators are designed into one device and are extremely helpful for renal surgery. The end of the suction/irrigator has two valves which activate each function. The irrigation fluid source is pressurized and activation of the valves allows inflow into the operative field. Suction is achieved by activation of the suction valve. Both the forces of suction and irrigation can be varied by adjustments in the degree of wall suction or pressurization of the irrigation source.

Other Devices

The argon beam uses argon gas and electric current to produce a coagulation effect. It does not dissect. The argon gas concentrates the spark at the tissue while forcing blood and other liquids away from the surface. The degree of coagulation is superficial. The harmonic scalpel uses high frequency vibrations (55,000 cycles) resulting in protein denaturing (primarily collagen). Heat is generated and it reaches 80-90° C. Depth of thermal damage is 0.5 to 1.5 mm. Both of these devices may be useful for partial nephrectomy.

Pediatric Laparoscopic Partial and Total Nephrectomy

Indications

The indications for pediatric laparoscopic total nephrectomy include small atrophic dysplastic kidneys, multicystic dysplastic kidneys, and small poorly functioning kidneys secondary to ureteropelvic junction obstruction or reflux nephropathy. The indications for a pediatric laparoscopic partial nephrectomy include a small atrophic or poorly functioning upper pole kidney in a duplex kidney secondary to obstruction, dysplasia or chronic pyelonephritis.

23

Patient Positioning

Patient positioning depends on the preferred surgical approach. A supine position is used for the transperitoneal approach, while a flank and prone position is used for the retroperitoneal approach. The retroperitoneal approach is becoming more popular since it avoids many of the potential complications associated with a transperitoneal approach, such as ileus, bowel injury, adhesions and bowel obstruction secondary to adhesions. In patients with prior abdominal surgery, a retroperitoneal approach obviates the concerns regarding bowel injury with abdominal reentry. The most common retroperitoneal approach is the lateral decubitus or flank position.

Trocar Placement and Procedure

Retroperitoneal Prone Approach

To facilitate the retroperitoneoscopic approach, patients are placed in the prone position following general anesthesia and decompression of the stomach, rectum and urinary bladder with indwelling catheters. Padding and support are provided laterally under the thorax, abdomen and hips. The exposed dorsal and lateral aspects of the trunk are prepared and draped in a sterile manner. Anatomic landmarks are identified and anticipated port sites are then marked (Fig. 23.1). A 1-1.5 cm. longitudinal skin incision is made at the costovertebral angle and lateral border of the sacrospinalis muscle (Fig. 23.1, port 1). The muscular fascia or lumbodorsal fascia is incised and held with a box stitch of 3-0 polyglactin suture. This suture will secure the 5 mm. cannula, sealing the pneumoretroperitoneum during dissection and aiding in the approximation of the fascia after cannula removal. Through this incision the retroperitoneum is bluntly dissected to allow insertion of the retroperitoneal dissecting device. A dissecting balloon is made by securing a finger of a sterile surgical glove to the end of a short 12 F catheter with a silk tie. The catheter tip is inserted beyond the lumbodorsal fascia, and depending on the size of the patient, 100-250 ml of warm normal saline is injected slowly to develop the retroperitoneal space. The system is left inflated for several minutes to promote dissection and hemostasis. The fluid is then withdrawn.

A 5 mm cannula is inserted into the port 1 site (Fig. 23.1) followed by insufflation of the retroperitoneum with CO₂ at a 15 mm Hg pressure limit. A 5 mm endoscope with a 0° lens is then passed and the retroperitoneum is inspected for bleeding. The 5 mm cannula is checked for appropriate depth of insertion and temporarily secured with the fascial box suture. Through port 1 the lateral peritoneal reflection is identified. Two 2 mm trocars are then placed under endoscopic guidance. The first is inserted at a point midway between the tip of the 12th rib and the iliac

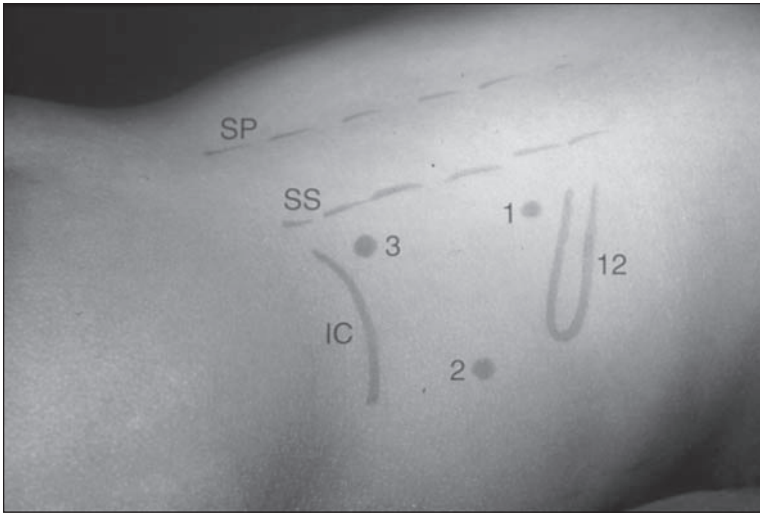


Figure 23.1. Anatomic and cannula placement sites for a retroperitoneal prone approach.

crest along the posterior axillary line (Fig. 1), such that it enters the retroperitoneum just dorsal to the lateral peritoneal reflection. The other 2 mm trocar is placed approximately 1 cm cephalad to the iliac crest at the lateral border of the sacrospinalis muscle (Fig. 23.1).

The ideal port for introduction of instrument or endoscope may vary based on the unique anatomy of each patient. Typically, dissection is best performed with the dissecting instruments inserted via ports 2 and 3 supported by visualization with a 5 mm 0° endoscope through port 1. Renal dissection begins at the lower pole of the kidney followed by mobilization of the lateral and cephalad aspects. Dissection is continued until the renal pelvis and hilar vessels are identified. With development of the pneumoretroperitoneum and dissection in the prone position, the kidney falls anteriorly and laterally improving hilar visualization. Traction on the proximal ureter or renal pelvis may optimize dissection of the renal hilum.

Following adequate dissection of the hilar vessels, a 2 mm endoscope is inserted through either port 2 or 3. This allows a 5 mm clip applicator to be inserted through port 1 and used to individually clip the artery and vein, respectively. Two clips are placed proximally and one distally prior to transection of each vessel. Traction on the proximal ureter facilitates dissection of the ureter distally and any further dissection needed to fully mobilize the kidney. In a non-refluxing system, the ureter is transected and dissection of the kidney is completed. In a refluxing or massively dilated system, complete nephroureterectomy is performed. The kidney is held securely at one pole with a large grasping forceps and extracted with the 5 mm cannula under vision afforded by the 2 mm endoscope. As needed, the cannula entry site is spread gently in order to facilitate extraction of the specimen. The 5 mm cannula is then replaced, the pneumoretroperitoneum is reduced to 4 mm Hg, and the operative

field is inspected for hemostasis. Following confirmation of satisfactory hemostasis, the cannulas are removed under vision. Skin incisions are closed with fine absorbable sutures and a sterile dressing is applied. The patient is returned to the supine position and indwelling catheters are removed prior to extubation.

Retroperitoneal Flank Approach

The patient is placed in the standard flank position. The retroperitoneoscopic approach begins by making a 1.5 cm transverse skin incision just anterior to the tip of the 12th rib (Fig. 23.2). The thoracolumbar fascia is identified and a 1 cm incision is made. Stay sutures are placed. Dissection is carried down to the retroperitoneal space with gentle finger dissection. The dilating balloon is inserted into the retroperitoneal space. The dilating balloon is made by securing the cut finger of a sterile surgical glove to the end of a 12 plastic catheter using a silk tie. Once placed in the retroperitoneum the balloon is expanded by instillation of 100-250 cc of sterile warm saline. The catheter is clamped for several minutes and the fluid withdrawn. When possible, the dilating balloon can be placed through a small opening in Gerota's fascia, which will facilitate exposure. Once the dilation of the retroperitoneal space is completed, the 5 or 10 mm Hasson cannula is introduced and the stay sutures are used to secure a snug fit around the trocar. Some cannulas have fascial retention balloons or adjustable conical sleeves that provide a better seal. The retroperitoneum is insufflated with carbon dioxide to a pressure of 15 mm Hg and the 5 or 10 mm zero degree rigid endoscope is inserted. The peritoneal reflection can be mobilized medially with gentle blunt dissection with the end of the endoscope. The second port is placed under direct vision at the intersection of the anterior axillary line and the tip of the 12th rib. The third port is placed 1 cm superior to the iliac crest in the midaxillary line. The ureter and lower pole of the kidney is identified. If Gerota's fascia has not been opened with the dilating balloon, it is now identified and incised. The ureter is identified and transected with cautery or divided between clips. The perirenal fat is dissected away for the kidney and the renal hilum is isolated. The vessels are clipped and transected. The surgical site is inspected for hemostasis under reduced intracavitary pressure of 4 to 6 mm Hg. The specimen is removed through the 10 mm port site, which may or may not be enlarged. The fascia is closed with interrupted sutures. The skin edges are reapproximated.

Supine Transperitoneal Approach

The surgical staff and monitor position can vary with this approach. Most often there are two monitors on each side of the patient. The surgeon and first assistant stand on one side while the second assistant (camera operator) stands on the opposite side. This coordinates the hand-eye movements of the two operative surgeons. Another variation places the operative surgeon and his first assistant on opposite sides of the patient, however the disorientation that results from opposing views must be overcome. A 5 or 10 mm trocar port is placed in the infraumbilical position by the open (Hasson) or Veress technique (Fig. 23.3). Once the infraumbilical port is placed, the abdomen is insufflated with CO₂ to obtain an intrabdominal pressure of 15 mm Hg. The pressure limit should be set at 15 mm Hg while the gas flow setting may be set at 4-5 L/minute. As gas dissipates through the trocar ports, a flow

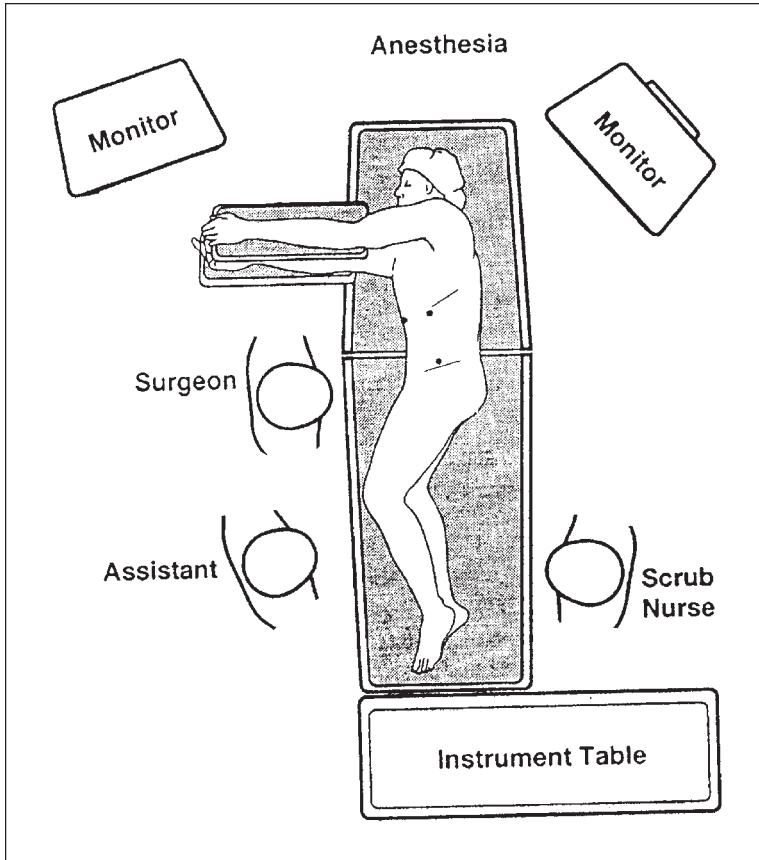


Figure 23.2. Staff and cannula placement for a retroperitoneal flank approach.

rate of 4-5 L/minute will quickly compensate to maintain an adequate pneumoperitoneum. While infraumbilical access is being obtained, the 5 or 10 mm 0° lens should be warmed by placing the distal-most portion the lens in warm saline. Whenever a cool object is placed in a warm moist environment, condensation occurs on the cooler object. The warming of the lens helps to reduce the temperature difference and reduce the condensation effect. Obviously, this occurs early in the surgical procedure, since the lens eventually equilibrates with the intrabdominal temperature. The second and third 5 mm ports are placed under direct vision in the positions outlined in Figure 23.3. Trocar sites and intrabdominal contents should be inspected for bleeding or injury.

Depending on the type of ports used and after checking for appropriate depth of insertion, some surgeons prefer to secure the ports to the abdomen by placing a fascial suture, which is tied to the port. This helps prevent dislodgment of the ports



Figure 23.3. Cannula placement sites in the supine patient undergoing a transperitoneal nephrectomy.

from the abdomen, which would result in a rapid loss of the pneumoperitoneum. The white line of Toldt is identified and incised so that the colon (ascending or descending) may be reflected medially. Gerota's fascia is identified and incised. The ureter is isolated and divided between two clips placed by a 5 mm endoscopic clip applicator (Fig. 23.4). The renal hilum is carefully identified and the renal artery and vein are

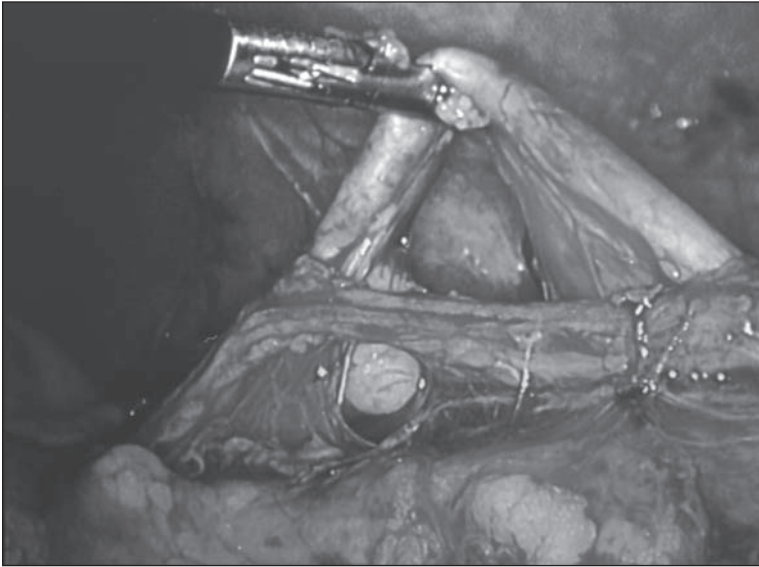


Figure 23.4. Identification and isolation of the ureter.

isolated (Fig. 23.5). Two 5 mm clips should be applied medially (great vessel side) and one placed laterally. The renal artery and vein are divided. The renal hilum is inspected for hemostasis. The cysts of a multicystic kidney can be decompressed within the abdomen and the remnant specimen removed through the 10 mm infraumbilical port. While the specimen is extracted through this port, a 5 mm lens can be placed through one of the alternate port sites. For larger specimens, one port site of the surgeon's choosing may be enlarged to facilitate removal of the specimen. In general, larger specimens are removed through an enlarged curvilinear infraumbilical incision or a midline infraumbilical incision. Most of these nephrectomy specimens are sufficiently small to allow removal by one of these techniques. The renal fossa should be reinspected for hemostasis. It is helpful to temporarily reduce the intraabdominal pressure to 4-6 mm Hg while inspecting the surgical site. Theoretically, a higher intraabdominal pressure may prevent identification of a bleeding site due to the tamponade effect of the pneumoperitoneum. Once hemostasis is assured, the colon is placed back into position. The trocars are sequentially removed under direct vision and the fascial edges are reapproximated with one or two interrupted vicryl sutures. The skin edges are reapproximated with a subcuticular monocryl suture. A dry sterile dressing is applied. The patient is recovered from anesthesia and the orogastric and rectal tubes are removed.

Transperitoneal Flank Approach

In the flank position, the operative surgeon and his assistants stand on the abdominal side of the patient while the monitor is placed on the opposite side (Fig.23.6).

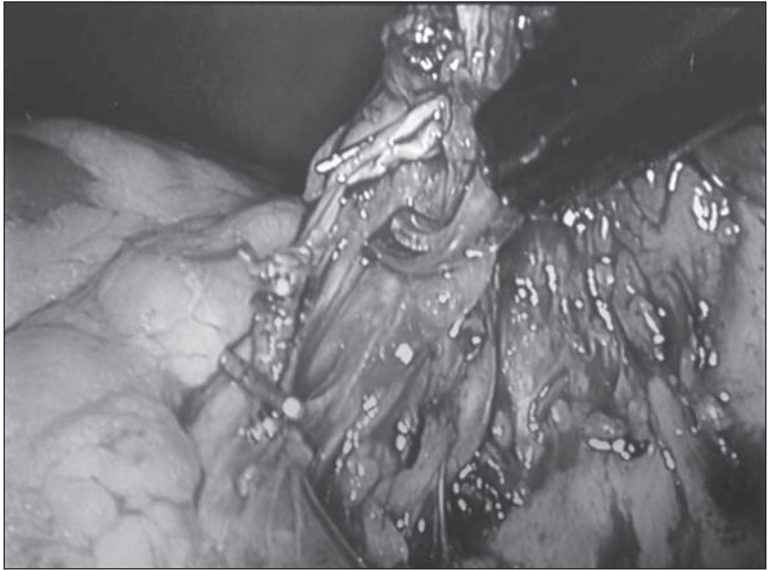


Figure 23.5. Identification, clipping and transection of the renal vessels.

This coordinates and optimizes the hand-eye coordination among the surgical team. In addition, it minimizes the disorientation that occurs with opposing views. Once positioned, the patient is prepped and draped. Trocar placement begins with the insertion of a 5 or 10 mm trocar in the infraumbilical position using the open or Hasson technique. Once the infraumbilical port is placed, the abdomen is insufflated with CO₂ to obtain an intrabdominal pressure of 15 mm Hg. The pressure limit should be set at 15 mm Hg while the gas flow setting is set at 4-5 L/minute. As gas dissipates through the trocar ports, a flow rate of 4-5 L/minute will quickly compensate to maintain an adequate pneumoperitoneum. While infraumbilical access is being obtained, the 5 or 10 mm 0° lens should be warmed by placing the distal-most portion of the lens in warm saline. The warming of the lens helps to reduce the condensation effect. The second and third 5 mm ports are then placed under direct vision in the positions outlined in Figure 23.6. Trocar sites and intrabdominal contents should be inspected for bleeding or injury.

Depending on the type of ports used and after checking for appropriate depth of insertion, the ports may be secured to the abdomen by placing a fascial suture, which is then tied to the port. This helps prevent dislodgment of the port from the abdomen, thus avoiding a rapid loss of the pneumoperitoneum.

The same procedure is performed as described above using the supine transperitoneal approach.

Pediatric Laparoscopic Pyeloplasty

Indications

Indications for laparoscopic pyeloplasty are the same as for open pyeloplasty. At the current time, laparoscopic pyeloplasties have only been performed at a few centers. There are only four reports of pediatric laparoscopic dismembered pyeloplasty in the literature since the original description. This procedure is performed by a transperitoneal approach. Due to instrument limitations and spatial constraints, the retroperitoneal approach is not recommended. Perhaps as new suture materials and techniques become available, the retroperitoneal approach may be feasible. In Tan's experience with 18 children with the transperitoneal approach, which is the most current and largest series, a success rate of 87% was achieved. The age of the patients ranged from 3 months to 15 years. There was no conversion to open surgery and one patient suffered a trocar hematoma which resolved with conservative treatment. This procedure is particularly challenging in infants due to the small caliber ureters and limitations of available sizes of pediatric stents which compound the technical challenges.

Patient Positioning

Patients may be positioned in the supine or flank position as described above in the Nephrectomy section.

Trocar Placement and Procedure

There is currently no standard method for the performance of laparoscopic pyeloplasty. The best method, size and placement of trocars and the use of suture material remains to be determined. In general, the same principle of the open dismembered pyeloplasty, as popularized by Andersen and Hynes, is followed. Most reports to date have described the transperitoneal route. However, there appears to be an advantage in performing the pyeloplasty through a retroperitoneal approach in order to avoid the long-term complication of adhesions or the short-term complication of inadvertent bowel injury during the surgical procedure. Current proponents of the transperitoneal approach cite the benefit of added room necessary for maneuvering during intracorporeal suture tying. In addition, they discount the risk of adhesions, citing minimal mobilization of the colon at its lateral reflection and stress that this mobilization is no greater than that performed for a laparoscopic orchiopexy. Long term follow-up will ultimately settle this issue. To date, reports using the retroperitoneal approach have been confined to adults. With refinements in technique, instrumentation, and suture techniques, it may be possible to perform this surgery through the retroperitoneal approach in children.

Preoperatively the patient is given an enema to empty the colon. After the induction of general anesthesia, a Foley catheter and nasogastric tube are placed. In addition, some have advocated the use of a rectal tube which may decompress the large bowel of gas. The patient is placed in the flank position (Fig. 23.2) or the supine position. The surgical prep area should extend from the xiphoid to the pubis and from midaxillary line to the contralateral midclavicular line. Access is first obtained by the Hasson technique via an infraumbilical or supraumbilical incision. After placement of a 10 mm trocar, the abdomen is insufflated with CO₂ to 15 mm Hg.

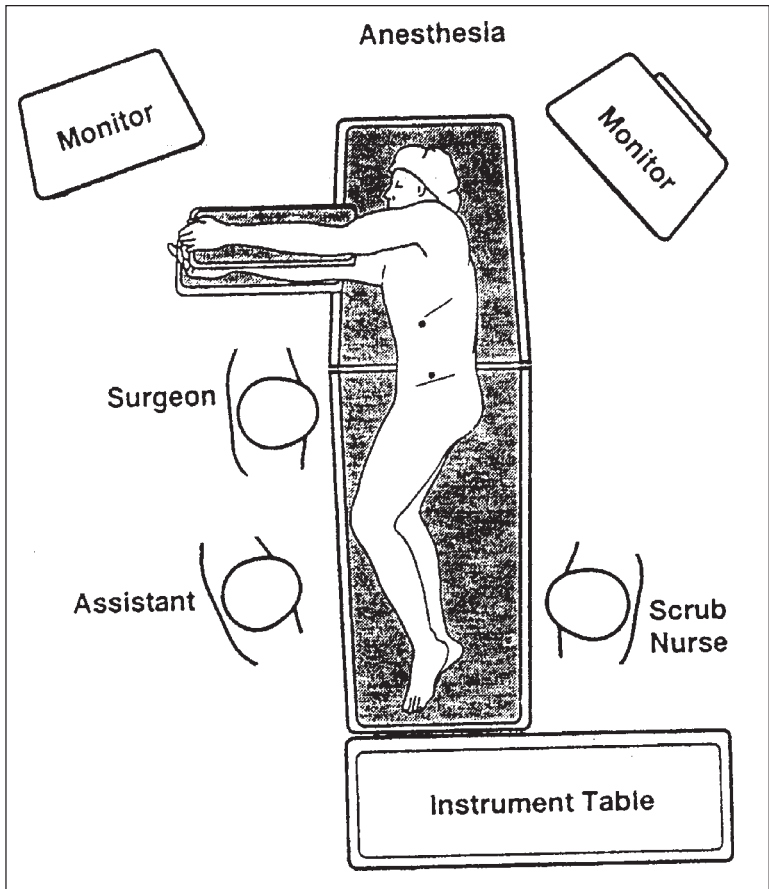


Figure 23.6. Positioning of equipment and cannula sites for a transperitoneal flank approach.

Under direct vision, two additional trocars (5 mm) are placed: one in the upper quadrant and one in the lower quadrant (Fig. 23.3). This wide spacing of the trocars facilitates intracorporeal suture tying.

Both surgeons and the nurse assistant are positioned on the abdominal side of the patient with the monitor on the opposite side or backside of the patient. Having both the operative surgeon and the assistant in this position optimizes hand-eye coordination and minimizes disorientation due to opposing views.

Gerota's fascia is identified and incised. After the ureter, renal pelvis and UPJ are exposed, a transabdominal holding suture (3-0 Prolene on a straight needle) is placed by passing the needle through the anterior abdominal wall, through the renal pelvis and back out through the anterior abdominal wall. The extracorporeal holding suture

serves to stabilize the renal pelvis during manipulation and suturing, while avoiding the placement of an additional trocar port. The abnormal UPJ is excised as is normally done in the open procedure. The ureter is spatulated. The anastomosis is created using 5-0 or 6-0 sutures (colored is best for viewing since clear or colorless suture is hard to identify). The authors' preference is for an interrupted suture anastomosis to eliminate the 'gathering' of the suture line which can occur with a running suture line.

Placement of a double J stent for this procedure has been well described. A flexible guidewire is passed through the anterior abdominal wall and down the ureter into the bladder just prior to completing the UPJ anastomosis. A double pigtailed catheter of appropriate length is placed over the guidewire and into the bladder. The guidewire is removed and the other end of the pigtail catheter is placed into the renal pelvis. The anastomosis is completed and the renal pelvis holding suture is removed. The two 5 mm trocars are removed under direct vision while the entry sites are examined for hemostasis. The abdomen is partially desufflated and the operative site and trocar sites are again examined for hemostasis. The umbilical trocar is removed. The fascial edges of the trocar sites are reapproximated with 3-0 vicryl sutures. The skin edges are reapproximated and dressed with commercially available surgical adhesive tape. The Foley catheter and double J pigtail stent are removed as per the surgeon's preference. To date, all reported pediatric laparoscopic pyeloplasties have used some form of stent (double J stent) or diversion (percutaneous nephrostomy). Since many pediatric urologists perform stentless open pyeloplasties, it stands to reason that laparoscopic pyeloplasties may also be performed without stents or diversion. As experience is gained, this will likely occur.

Postoperative Care

The length of bladder catheterization will depend on the intraoperative and postoperative analgesia. With the use of caudal or epidural anesthesia, the Foley catheter may be removed soon after the surgical procedure. It is advisable to continue bladder drainage while the epidural anesthesia is employed. Most patients should not need postoperative epidural anesthesia, and in fact, experience minimal discomfort following the laparoscopic surgery. Most discomfort experienced is minimal and related to the port sites. Typically, acetaminophen is sufficient for postoperative pain management in young children. Some patients may experience a temporary ileus which is treated conservatively. Patients who do not develop an ileus are often ready for discharge within 12-24 hours.

Conclusion

It appears that laparoscopic pediatric renal surgery may become an attractive alternative to open surgery and more widely utilized as more experience is gained. Currently, in reconstructive renal surgery, such as laparoscopic pyeloplasty, the success rate approaches but does not equal that of open surgery. What is clear is that laparoscopic renal surgery is technically feasible, reliable, and safe. Its efficacy is approaching conventional open renal surgery. As improvements in instrumentation continue and innovative suturing techniques develop, laparoscopic surgery may become the standard approach for most renal pathologies.

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Thoracoscopy in Infants and Children

Steven S. Rothenberg

Introduction

Thoracoscopy is a technique that has been in use since the early 1900s but has undergone an exponential increase in popularity and growth over the last decade. The first experience in humans was reported by Jacobeus in 1910 and consisted of placing a cystoscope inserted through a rigid trocar into the pleural space to lyse adhesions and cause complete collapse of a lung as treatment for a patient with tuberculosis. During the next 70 years thoracoscopy gained some favor, primarily in Europe, for the biopsy of pleural based tumors and limited thoracic explorations in adults.

Rodgers et al in the 1970s and 1980s reported the first significant experience in children. He used equipment modified for pediatric patients to perform biopsies, evaluate various intrathoracic lesions, and perform limited pleural debridement in cases of empyema. However it wasn't until the early 1990s with the dramatic revolution in technology associated with laparoscopic surgery in adults, that more advanced diagnostic and therapeutic procedures have been performed in children. The development of high-resolution microchip and now digital cameras, smaller instrumentation, and better optics has enabled pediatric surgeons to perform even the most complicated intrathoracic procedure thoracoscopically.

Indications

Today there are a wide variety of indications for thoracoscopic procedures in children (Table 24.1) and the number continues to expand with advances and refinements in technology and technique. Currently, thoracoscopy is being used extensively for lung biopsy and wedge resection in cases of interstitial lung disease (ILD) and metastatic lesions. More extensive pulmonary resections including segmentectomy and lobectomy have also been performed for infectious diseases, cavitary lesions, bullous disease, sequestrations, lobar emphysema, congenital adenomatoid malformations, and neoplasm. Thoracoscopy is also extremely useful in the evaluation and treatment of mediastinal masses. It provides excellent access and visualization for biopsy and resection of mediastinal structures such as lymph nodes, thymic and thyroid lesions, cystic hygromas, foregut duplications, ganglioneuromas, and neuroblastomas. Other advanced intrathoracic procedures such as decortication for empyema, patent ductus arteriosus closure, repair of hiatal hernia defects, esophageal myotomy for achalasia, thoracic sympathectomy for hyperhidrosis, anterior spinal fusion for severe scoliosis and, and most recently primary repair of esophageal atresia have also been described in children.

Table 24.1. Histological diagnosis of ILD: procedures performed thoracoscopically in children

Lung biopsy
Wedge or segmental resection
Lobectomy/Pneumonectomy
Resection of bullae
Pleurodesis/Pleurectomy
Decortication
Biopsy/Resection of mediastinal masses
Thymectomy
Thyroidectomy
Parathyroidectomy
Resection of foregut duplication
Esophageal myotomy
Repair esophageal atresia
Repair diaphragmatic hernia
Diaphragmatic plication
Aortopexy
Repair bronchopleural fistula
Sympathectomy
Thoracic duct ligation
Anterior spinal fusion
Placement of central venous line

Preoperative Workup

The preoperative work-up varies significantly depending on the procedure to be performed. Most intrathoracic lesions require routine radiographs as well as a CT or MRI scan. A thin cut high resolution CT scan is especially helpful in evaluating patients with ILD as it can identify the most affected areas and help determine the site of biopsy (Fig. 24.1) as the external appearance of the lung is usually not helpful. CT guided needle localization can also be used to direct biopsies for focal lesions which may be deep in the parenchyma and therefore not visible on the surface of the lung during thoracoscopy. This is usually performed just prior to the thoracoscopy with the radiologist marking the pleura overlying the lesion with a small blood patch or dye (Figs. 24.2a and 24.2b). On occasion a wire may be placed as in breast biopsies, but these may become dislodged during collapse of the lung at the time of surgery. As intraoperative ultrasound imaging improves this may provide a more sensitive way for the surgeon to detect lesions deep to the surface of the lung and make-up for the lack of tactile sensation. Unfortunately in its current state this technology is still unreliable. A MRI scan may be more useful in evaluating vascular lesions or masses which may arise from or encroach on the spinal canal or in the case of vascular rings. These studies can be extremely important in determining positioning of the patient and initial port placement.

Another major consideration for the successful completion of most thoracoscopic procedures is whether or not the patient will tolerate single lung ventilation thus allowing for collapse of the ipsilateral lung to ensure adequate visualization and room for manipulation. Unfortunately there is no specific preoperative test that will yield this answer. However most patients, even those who are ventilator dependent,

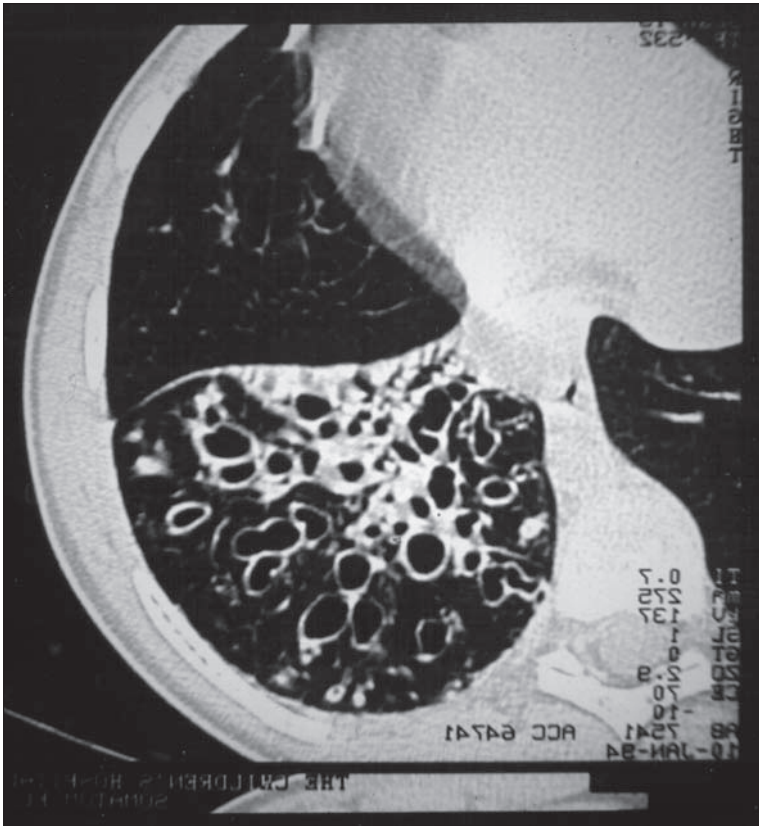


Figure 24.1. CT scan of patient with interstitial lung disease. The areas of greatest involvement can be identified for biopsy.

can tolerate short periods of single lung ventilation which allows adequate time to perform most diagnostic procedures such as lung biopsy. In cases where single lung ventilation cannot be tolerated other techniques may be used and these will be discussed later.

Preoperative Preparation

Anesthetic Considerations

While single lung ventilation is achieved relatively easily in adult patients using a double-lumen endotracheal tube, the process is more difficult in the infant or small child. The smallest available double-lumen tube is a 28 F, which generally cannot be used in a patient under 30 kg. Another option is a bronchial blocker. This device contains an occluding balloon attached to a stylet on the side of the endotracheal tube. After intubation this stylet is advanced in the bronchus to be occluded

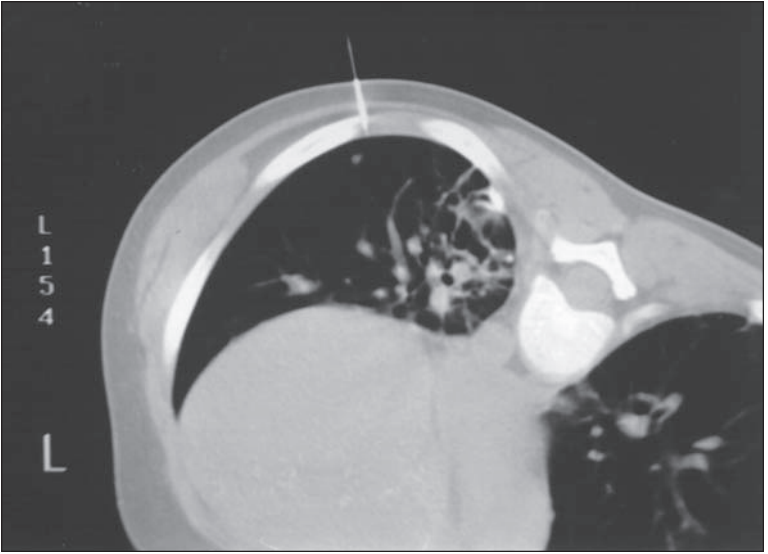


Figure 24.2a. Needle localization of presumed metastatic lesion under CT guidance.

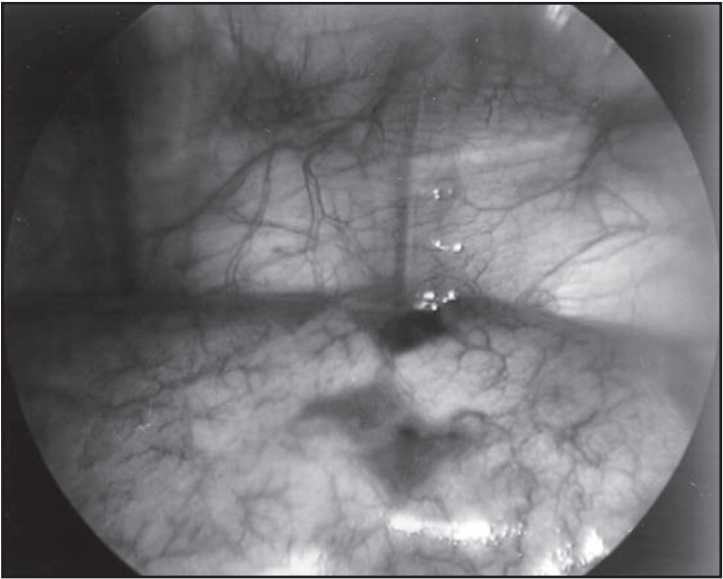


Figure 24.2b. Small blood patch visible on pleural surface marking the underlying nodule.



Figure 24.3. Patient placed in left lateral decubitus position for lung biopsy.

and the balloon is inflated. Unfortunately size is again a limiting factor as the smallest blocker currently available is 6.0. For the majority of cases in infants and small children a selective mainstem intubation of the contralateral bronchus with a standard un-cuffed endotracheal tube is effective. This can usually be done blindly without the aide of a bronchoscope simply by manipulating the head and neck. It is also important to use an endotracheal tube one-half to one size smaller than the anesthesiologist would pick for a standard intubation or the tube may not pass into the mainstem bronchus, especially on the left.

At times this technique will not lead to total collapse of the lung as there may be some overflow ventilation because the endotracheal tube is not totally occlusive. If adequate visualization cannot be obtained then a low flow (1 L/min), low pressure (4 mm/Hg) CO₂ infusion can be used during the procedure to help keep the lung compressed. This requires the use of a valved trocar rather than non-valved port (Thoracoport). In general hemodynamic and ventilation problems have not arisen as a result of this small amount of positive intrathoracic pressure. This technique can also be used on patients who cannot tolerate single lung ventilation. By using small tidal volumes, lower peak pressures, and a higher respiratory rate, enough collapse of the lung can be achieved to allow for adequate exploration and biopsy. Whatever method is chosen it is imperative that the anesthesiologist and surgeon have a clear plan and good communication to prevent problems with hypoxia and excessive hypercapnia, and to ensure the best chance at a successful procedure.

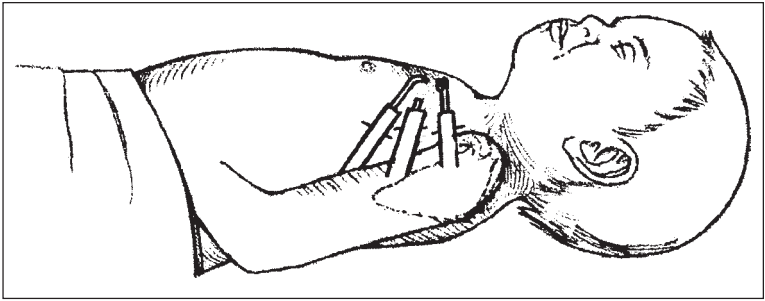


Figure 24.4. Patient in a modified supine position with the affected side elevated 30 degrees to allow access to the mid- and posterior axillary lines.

Positioning

Positioning depends on the site of the lesion and the type of procedure. Most open thoracotomies are performed with the patient in a lateral decubitus position (Fig. 24.3). Thoracoscopic procedures should be performed with the patient in a position that allows for the greatest access to the areas of interest and uses gravity to aid in keeping the uninvolved lung or other tissue out of the field of view.

For routine lung biopsies or resections, the patient is placed in a standard lateral decubitus position (Fig. 24.3). This position provides for excellent visualization and access to all surfaces of the lung. For anterior mediastinal masses the patient should be placed supine with the affected side elevated 20-30° (Fig. 24.4). This allows for excellent visualization of the entire anterior mediastinum while keeping the lung posterior without the need for extra retractors. The surgical ports may then be placed in the anterior and mid-axillary lines with clear access to the anterior mediastinum. For posterior mediastinal masses, esophageal lesions, and work on the esophageal hiatus the patient should be placed in a modified prone position with the affected side elevated slightly (Fig. 24.5). This maneuver again allows for excellent exposure without the need for extra retractors. The patient can then be placed in Trendelenburg or reverse Trendelenburg as needed to help keep the lung out of the field of view.

Once the patient is appropriately positioned and draped the monitors can be placed in position. For most thoracoscopic procedures it is advantageous to have two monitors, one on either side of the table. The monitors should be placed near the head of the table at or near the level of the patient's shoulder. For procedures primarily in the lower third of the thoracic cavity the monitors should be placed near the foot of the table or at the level of the patients hips. The majority of operations can be performed with the surgeon and one assistant. The surgeon should stand on the side of the table opposite the area to be addressed so that he can work in line with the camera as he performs the procedure. In most lung cases such as biopsies, it is preferential to have the assistant on the same side of the table as the surgeon so that he is not working in a paradox (against the camera), as he is responsible for operating the camera and providing retraction as necessary (Fig. 24.6). This concept is even more important when the field of dissection is primarily on one side. Cases such as mediastinal masses, isolated lung lesions, or more complicated

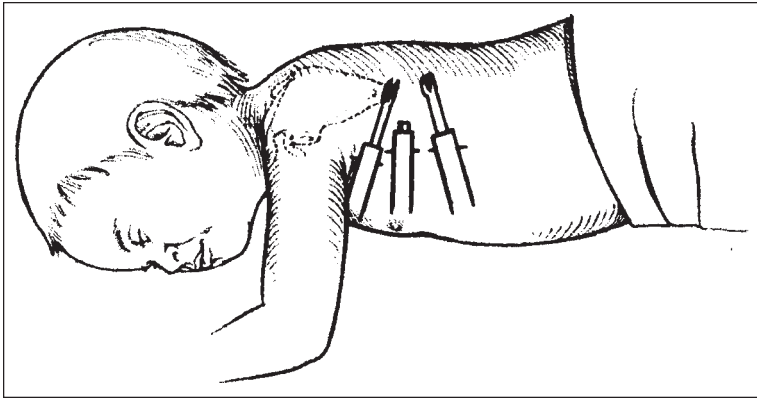


Figure 24.5. Patient in a modified prone position with the affected side elevated 30 degrees to allow access to the anterior and mid axillary lines.

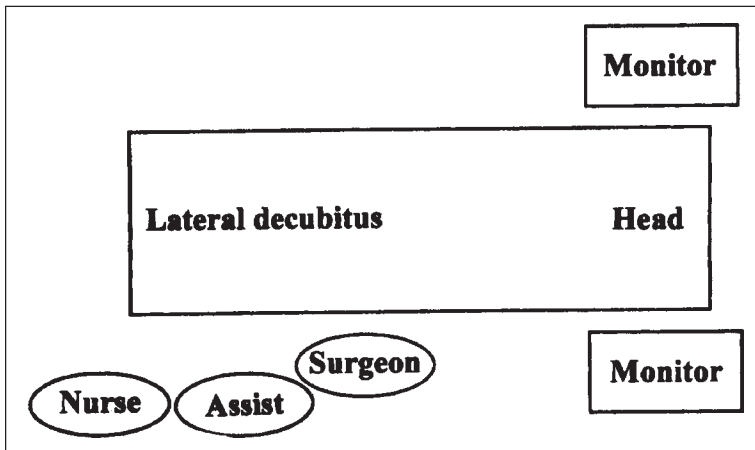


Figure 24.6. Standard O.R. set-up for a thoracoscopic lung biopsy or resection.

resections require greater surgical skill and it is imperative that both are working in line with the field of view to prevent clumsy or awkward movements.

Trocar Placement

Positioning of the trocars varies widely with the procedure being performed and the site of the lesion. Thoughtful positioning of the trocars is more important than with laparoscopic surgery because the chest wall is rigid and therefore the mobility of the instruments will be somewhat restricted as compared to in the abdomen. The most commonly performed procedures such as lung biopsy for ILD or decortication

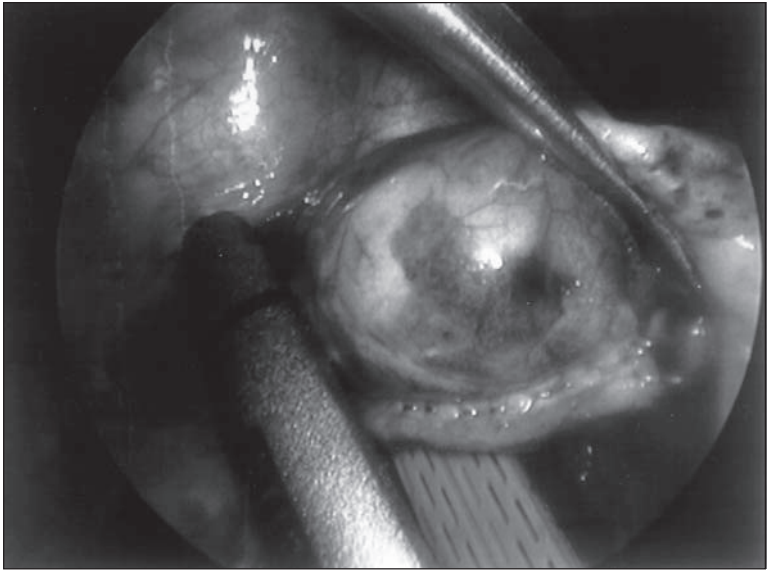


Figure 24.7. Endoscopic stapler being used to perform a wedge resection in a patient with metastatic disease.

for empyema may require wide access to many areas in the thoracic cavity and therefore the ports are placed in such a fashion as to facilitate this. However this may result in some degree of paradox during portions of the procedure. Other operations are directed towards a very restricted area and therefore the trocars are placed to allow for the best visualization and access to this specific spot.

For example with lung biopsies the trocars should usually be placed between the 4th and 8th intercostal space. The camera port is usually in the mid-axillary line at the 5th or 6th interspace. If an endoscopic stapler is being used it requires a 12 mm port and therefore should be placed in the lowest interspace possible especially in smaller children as these are the widest. If the lesion is anterior it should be positioned closer to the posterior axillary line and *visa-versa*. The third or grasping port is placed closer to the lesion and provides traction on the lesion during biopsy. This arrangement allows the surgeon, camera, and primary working port to be in line with the area to be biopsied. The mid-axillary port should be placed first to allow for modification of the other two ports once an initial survey of the chest cavity has been completed. A triangular arrangement of the trocars has also been recommended because it allows for rotation of the telescope and instruments between the three ports giving excellent access to all areas. However the surgeon can find himself working against the camera, a situation which can make the simplest procedure very difficult. Generally trocar placement can be tentatively planned based on preoperative imaging studies and then modified once the initial trocar is placed.

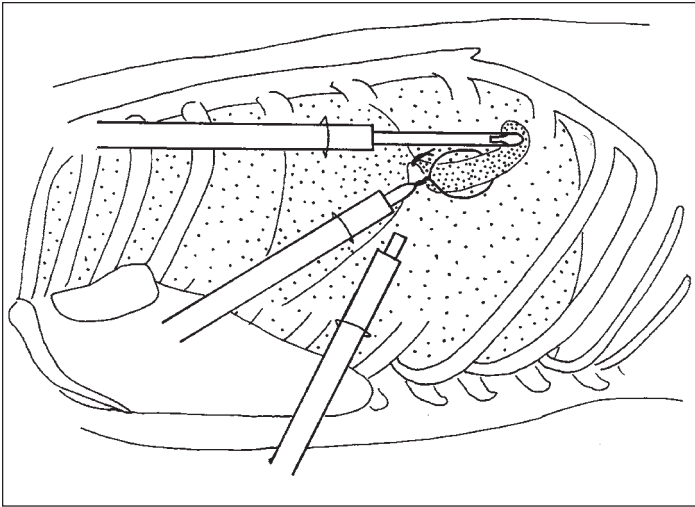


Figure 24.8A. Schematic drawing of endo-loops being applied for lung biopsy.

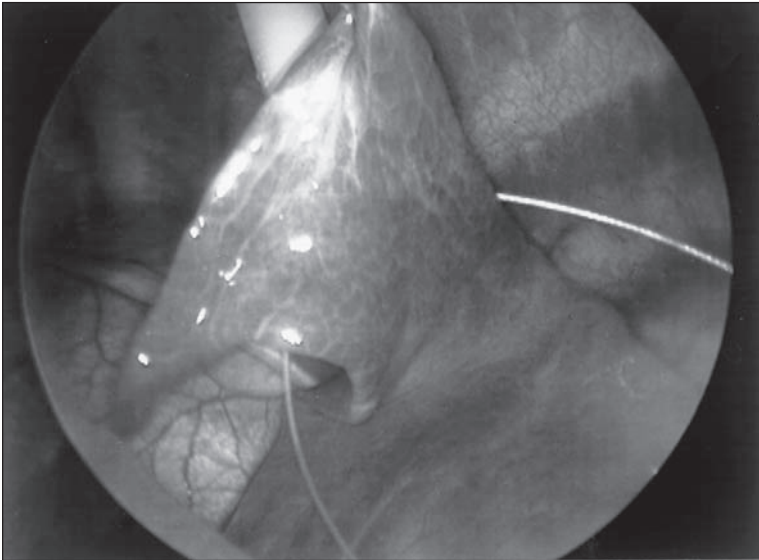


Figure 24.8B. Actual photo of an endo-loop being used to snare a lung specimen.

Instrumentation

The equipment used for thoracoscopy is basically the same as that for laparoscopy. In general 5 mm and 3 mm instrumentation is of adequate size and therefore 5 mm and smaller trocars can be used. In most cases valved trocars are used for the reasons previously discussed. Basic equipment should include 5 mm and 30° lenses. If procedures are being performed in smaller children and infants, it is also helpful to have smaller lenses such as a short (16 to 18 cm) 3 or 4 mm wide-angle 30° scopes and specifically designed shorter instruments. These tools enable the surgeon to perform much finer movements and dissection allowing advanced procedures to be performed in infants as small as 2 kg. A high resolution microchip or digital camera and light source are also extremely important to allow for adequate visualization especially when using smaller scopes which transmit less light. Basic instrumentation should include curved dissecting scissors, curved dissectors, atraumatic clamps (i.e., 3 and 5 mm atraumatic bowel clamp), fan retractor, a suction/irrigator, and needle holders. Disposable instrumentation which should be available including hemostatic clips, endoloops (pre-tied ligatures), and an endoscopic linear stapler. The linear stapler is an endoscopic version of the GIA used in open bowel surgery. It lays down 6 to 8 rows of staples and divides the tissue between them, providing an air and water tight seal. This is an excellent tool for performing wedge resections of the lung but unfortunately it's current size requires placement of a 12 mm trocar precluding its use in patients much under 10 kg because of the limited size of their thoracic cavity. There are also a number of energy sources available, which provide hemostasis and divide tissue. These include monopolar and bipolar cautery, the ultrasonic coagulating shears, and the Ligasure (Valleylab), all of which can be helpful in difficult dissections.

Lung Lesions

Lung biopsy is the most common thoracoscopic procedure performed and it will be described here in detail to illustrate basic techniques. The side for the biopsy is chosen based on CXR and CT scan findings. Under general anesthesia single lung ventilation is obtained as previously described. The patient is then placed in a lateral decubitus position and prepped and draped. If it is necessary to rely on a mainstem intubation or if the patient cannot tolerate one lung ventilation, a low flow (1 L/min), low pressure (4 mm Hg) insufflation with CO₂ can help collapse of the lung allowing for better visualization. In these cases the chest should first be pierced with a Veress needle to collapse the lung and then valved ports should be used to help maintain the slight tension pneumothorax. In general three trocars are sufficient and the trocars are placed as previously described. The first trocar is always placed in the mid-axillary line in the 5th or 6th intercostal space for the initial survey and also because this is unlikely to cause injury to the lung, diaphragm or other structures. After the initial survey the other two trocars are placed. In small children all 3 or 5 mm ports are used. In children near 10 kg or larger a single 12 mm port is placed so that the stapler may be used (Fig. 24.7). If a biopsy is being taken from the ventral surface of the lung, the scope should be placed in the mid-axillary trocar, the grasper in the anterior port, and the stapler in the inferior and posterior site. For biopsies on the posterior surface of the lung the position of the scope and grasper are reversed. In smaller patients whose chest cavity cannot accommodate the stapler, endoloops are used to snare and ligate sections of lung. Two consecutive loops are placed at the

base of the specimen and the tissue is sharply excised distal to the ligatures (Figs. 24.8A and 24.8B). This provides a hemostatic and airtight seal equivalent to that obtained with the stapler. Specimens of 2 to 3 cm in size can be obtained in this manner and are more than adequate for diagnosis. Biopsies can easily be obtained from all five lobes using this technique.

For metastatic lesions trocar placement is altered depending on the site of the lesion. Although most of these nodules are peripheral, lesions less than one centimeter in diameter or deeper in the parenchyma of the lung may not be readily visible on the surface of the lung. In these cases preoperative localization as previously described should be carried out. At the time of surgery with the lung collapsed the marked area can easily be identified. If the lesion itself is not visible then the area underlying the bloodstain can be wedged out. A frozen section should be obtained to ensure the lesion is included with the specimen. Ongoing improvements in endoscopic ultrasound probes should eventually make this the technique of choice for localization.

Resection of bullae or infectious cavitory lesions can be excised using a similar technique (Fig. 24.9). Any potentially malignant or infectious lesion that will not fit through the inner channel of the trocar should be placed in an endoscopic specimen bag to prevent possible seeding. Once the intrathoracic procedure has been completed a small chest tube is placed through one of the trocars and the collapsed lung is ventilated. In most cases where there is no concern over adequate hemostasis, chyle leak, or esophageal perforation the chest tube can be removed prior to extubation in the operating room if no evidence of any air leak is present. This avoids the considerable discomfort associated with the chest tube in the postoperative period. A chest x-ray is obtained in the recovery room, and if the lung is fully expanded no further follow-up films should be necessary.

Mediastinal and Esophageal Lesions

In dealing with extra pulmonary lesions such as mediastinal masses or esophageal pathology the patient should be positioned to allow gravity to retract the lung out of the field of view. The goal in trocar placement is to put the telescope in a position that allows the best direct visualization of the area to be addressed. The working ports are then placed so that the surgeon is working in-line with the camera. The trocars should not be placed too close together otherwise the instruments and telescope will end up “dueling” making the dissection much more difficult. If possible the scope should be placed in a position superior to the working ports to avoid this problem. A 30° scope may be helpful when the working space is limited. When working in the posterior mediastinum or on the esophagus it is useful to have a flexible gastroscope or lighted bougie in the esophagus during the dissection. This helps in identifying the esophagus by illumination within the lumen and by palpation of the scope with the thoracoscopic instruments. It may also be useful in identifying any iatrogenic injuries to the esophagus. This is especially true in performing a Heller myotomy for achalasia. Having the esophagoscope in place during the myotomy not only helps identify the esophagus and check for mucosal perforations, but internal visualization can help to determine when the myotomy has been extended far enough distally. This is evident by the relaxation of the LES as seen intra-luminally. This technique should help prevent an incomplete myotomy. The

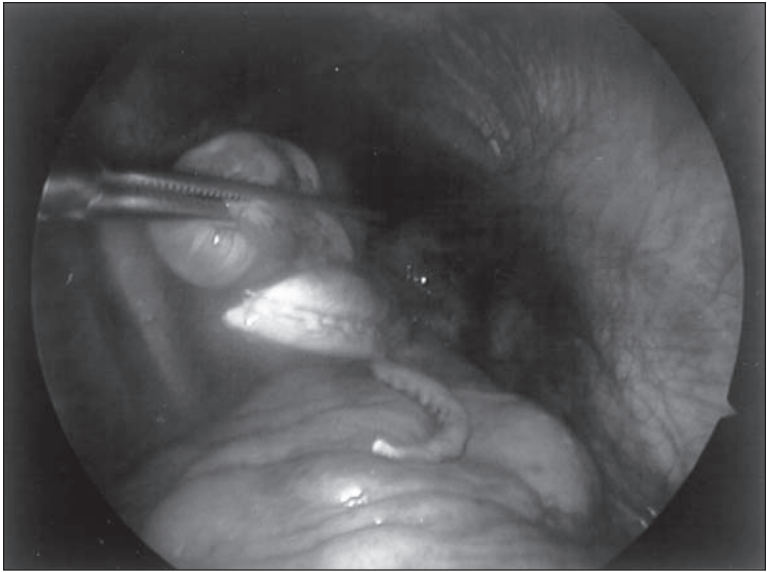


Figure 24.9. Stapler being used to resect an apical bleb in a patient with a spontaneous pneumothorax.

myotomy can be performed using a number of different instruments but most surgeons find a hook cautery works extremely well to tease the circular muscles up away from the submucosa preventing mucosal injury. The only question is whether it is appropriate to perform the myotomy without the addition of a partial fundoplication to prevent postoperative gastroesophageal reflux. The same exposure can be used to approach the esophageal hiatus in cases of hiatal or paraesophageal hernia. This is especially useful in patients who have undergone a previous abdominal fundoplication and whose wrap is intact but has herniated into the mediastinum. This technique allows the surgeon to approach the hiatus without having to go through a previously operated field and avoids the need of taking down the wrap to get adequate exposure. Both the right and left crus can be exposed from the left chest and an excellent posterior repair can be performed (Fig. 24.10).

Other esophageal procedures that have been successfully completed and reported include resection of duplications, diverticulum, and esophageal wall tumors. Repair of esophageal perforations and most recently a successful repair of a primary esophageal atresia and a newborn with tracheo-esophageal fistula have also been reported. These procedures was accomplished using 3 mm instruments and a combination of intracorporeal and extracorporeal suturing techniques, thus proving that not only resections but also reconstructive surgery can be safely performed even in infants.

The entire anterior mediastinum can be well visualize thoracoscopically and provides excellent access to anterior mediastinal, peritracheal and hilar adenopathy. This is an excellent technique for node biopsy and can avoid a more invasive anterior

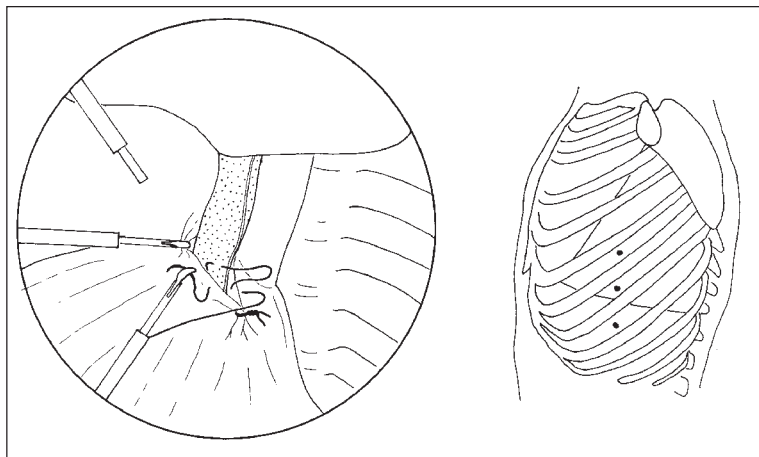


Figure 24.10. Schematic drawing of a thoracoscopic approach to the esophageal hiatus. The right and left crus are identified and a posterior crural repair performed.

mini-thoracotomy or a more limited and dangerous mediastinoscopy, which provides far less visualization and access. These biopsies can usually be performed with three 3 mm or 5 mm ports. The patient is in a modified supine position and the trocars are placed between the 3rd and 5th interspace and between the anterior and mid-axillary line. Thymic and thyroid tumors as well as teratomas can also be excised using this approach with excellent results. Occasionally a mini-thoracotomy is necessary to remove the specimen.

Video Assisted Thoracoscopic Surgery (VATS)

Some intrathoracic operations are not amenable to a pure thoracoscopic approach through trocars alone, either because of the size of the lesion or because of the limitations of the current equipment. Certain operations such as formal lobectomies, total esophagectomies, and resection of large tumor masses may require a combined approach using two to three thoracoscopic ports in addition to a mini-thoracotomy (5 to 6 cm). The thoracotomy incision can be performed using a muscle sparing technique thereby preserving the majority of the benefits of a thoracoscopic approach. However a rib spreader should not be used if at all possible, as these retractors are a source of significant postoperative pain. Recently the development of new linear staplers with a much wider jaw opening and which can articulate have made ligation and division of the main pulmonary vessels and bronchus much easier and safer. These staplers along with devices such as the Ligasure have made formal lobectomies, especially lower lobe, technically feasible and in many cases have obviated the need for even a mini-thoracotomy.

To perform a lower lobectomy the patient is placed in a lateral decubitus position. It is vital for these cases that good single lung ventilation be obtained. The initial port is placed in the mid-thorax at approximately the anterior axillary line. This allows the surgeon to evaluate the major fissure and plan the other port placements. A single

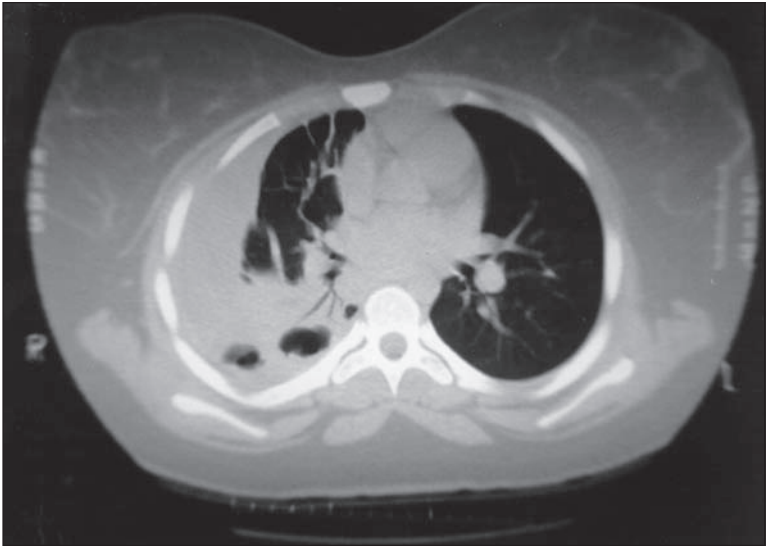


Figure 24.11. CT scan in a child with a large empyema. The large pleural peel and collapsed lung are easily identified.

12 mm port is necessary to insert the Endo-GIA and this should be placed in approximately the 6th or 7th intercostal space near the anterior axillary line. This allows relatively easy access to the inferior pulmonary vein and to the major fissure. The stapler can then be used to complete the fissure, divide the pulmonary artery as it passes through the fissure, and divide the lower lobe bronchus.

Upper lobectomies are much more technically demanding because they require isolating and individually ligating the arterial branches to the upper lobe.

Decortication

Thoracoscopic decortication or debridement is another is perfectly suited to the pediatric patient. The indications for the timing and the type of intervention are greatly debated but recent data suggests early intervention may significantly decreased the morbidity and hospital stay in these children. The algorithm for intervention varies but in general we recommend a thoracoscopic approach if chest tube drainage becomes necessary. A preoperative CT scan or ultrasound is helpful in determining the extent of the pleural peel and effusion (Fig. 24.11). The degree of lung entrapment as depicted by the CT is often surprising and this information may help the surgeon proceed with what seems a more aggressive approach. The patient is placed in a lateral decubitus position to allow access to the entire thoracic cavity. Single lung ventilation is preferable but not imperative in these cases as the lung is already collapsed because of the inflammatory peel. In most cases two ports are adequate to perform the procedure. It is usually necessary to place one larger port (10 mm) so that the inflammatory peel can be removed. The ports should be placed at approximately the 5th or 6th intercostal space, one anteriorly and one posteriorly.

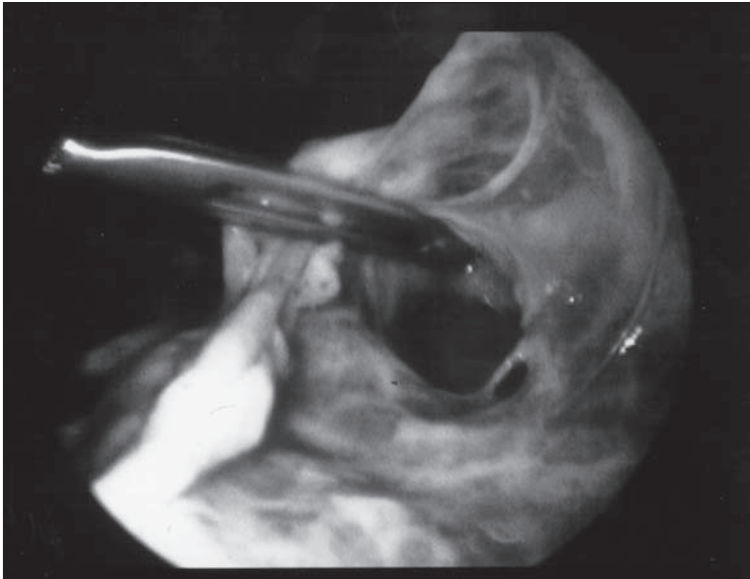


Figure 24.12. The peel is actually stripped away using an atraumatic clamp.

It is important to avoid placing the initial trocar too low, as the diaphragm in these cases is often high in the chest. A third port can be added as needed. If done early in the patient's course the inflammatory peel is soft and can be removed easily with an atraumatic bowel clamp (Fig. 24.12). A good suction/irrigation device is also imperative to get a good debridement of the pleural space. Often the initial dissection must be done blindly using either the scope or the suction irrigator to bluntly separate the lung from the chest wall and inflammatory peel. This can be done safely without injury to the lung. Once a space in the pleural cavity is created then the surgeon can use direct visualization to insure that there are no areas of loculated fluid and that the trapped lung is completely freed. A single chest tube is generally adequate for drainage and can usually be removed by the third or fourth postoperative day.

Some have advocated the use of urokinase or other agents to dissolve the inflammatory peel via a chest tube or in some cases intra- or postoperatively. While there may be a role for this adjuvant therapy its' efficacy is still yet to be determined. In many cases the child would still need a general anesthetic for the chest tube and urokinase insertion, and it seems unlikely that this technique would surpass debridement under direct visualization.

Patent Ductus Arteriosus (PDA) Closure

Closure of a persistent PDA has routinely been performed through a standard posterolateral thoracotomy incision with either suture ligation or vascular clip closure. Over the last decade an increasing experience with intravascular occlusive devices such as coils and plugs has been seen but this procedure is limited many

times by the size of the patient and the diameter of the ductus. Thoracoscopic closure offers an alternative to these two techniques and affords many of the same benefits as seen in other thoracoscopic procedures.

The procedure is performed with the patient in a right lateral decubitus position and three 3 mm ports and one 5 mm port are used to perform the surgery. Although the ductus is a posterior mediastinal structure the patient is kept in a lateral decubitus position to facilitate rapid conversion to an open thoracotomy should bleeding occur. The lung is retracted anteriorly and the ductus dissected free of the overlying pleura. The endoscope provides excellent visualization of the ductus and the recurrent laryngeal nerve, which should help prevent injury to this structure. A 5 mm endoscopic clip can then be safely applied to the ductus thereby occluding flow (Fig. 24.13). In some cases it is necessary to use a larger clip or perform a suture ligation. In these cases the 5 mm port is removed and a standard hemoclip can be placed through a widened trocar incision. To date excellent results have been obtained with this technique with minimal morbidity and a significant decrease in recovery and hospital stay.

Anterior Spinal Procedures

The treatment for severe scoliosis and kyphosis in children has often involved extensive surgical correction. These procedures are usually a joint endeavor between the pediatric surgeon and the pediatric orthopedist and have consisted of an anterior thoracotomy with discectomy and release followed by a posterior correction and fixation with rods. Many of these children already have severe pulmonary compromise and these procedures often caused severe morbidity and even death. Application of thoracoscopic techniques has allowed these patients to avoid a painful thoracotomy and decrease their pulmonary compromise and complications postoperatively.

The patient is placed in a modified lateral decubitus position tilted slightly prone to aid in keeping the lung out of the visual field. The anterior release can usually be performed through four or five trocar incisions 5 to 10 mm in size. Placement depends on the number and levels of the discs to be taken. In general the initial trocar is placed near the apex of the spinal deformity in approximately the mid-axillary line. The disc spaces can then be counted and the other ports positioned. All ports are kept in the mid-axillary line so that the scope and instruments can be interchanged as the surgeon moves up and down along the spine.

The first step is to expose the necessary disc spaces by incising and then clearing the overlying pleura at each level. Care is taken to preserve the segmental vessels. The orthopedic surgeon performs the discectomy using modified spine instrumentation and then packs the disc space with tri-cortical allograft to enhance fusion (Fig. 24.14). The disc spaces from T2 to T12 can be reached in this manner. Occasionally a small retractor must be placed through an inferior incision or port to retract the diaphragm to allow access to the lower thoracic vertebrae.

A single chest tube is placed through one of the lower trocar sites and the other port sites sutured closed. The operative time for this technique is now comparable to the open approach and recovery and the time chest tube drainage is required has significantly diminished. Some centers have even started placing anterior instrumentation this way but the experience is at this point very limited. Other spinal

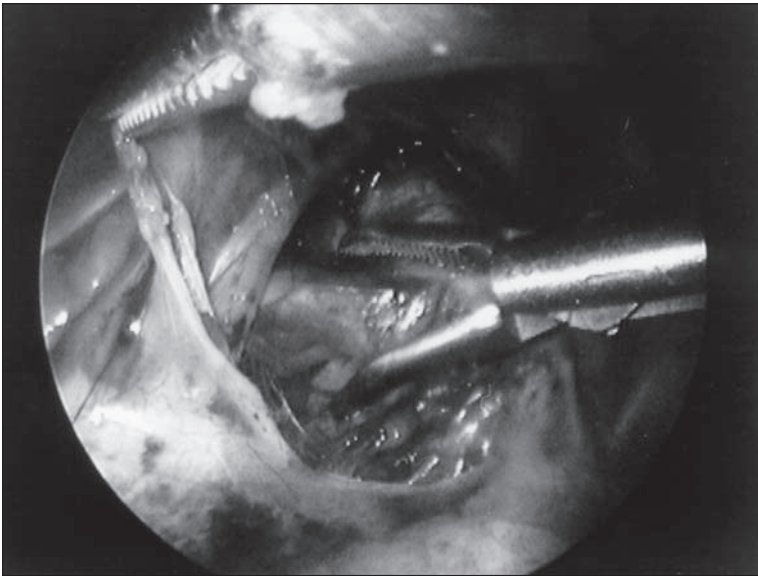


Figure 24.13. Patent ductus arteriosus outlined by atraumatic clamp.

procedures including vertebral body biopsies and hemivertebrectomy can also be accomplished in a similar fashion.

Postoperative Care

Postoperative care in the majority of patients is straightforward. Most patients following biopsy or limited resection can be admitted directly to the surgical ward with limited monitoring (i.e., a pulse oximeter for 6 to 12 h). These patients are generally 23 h observation candidates and a number are actually ready for discharge the same evening. If a chest tube is left in it can usually be removed on the first postoperative day. Pain management has not been a significant problem. Local anesthetic is injected at each trocar site prior to insertion of the trocar and then one or two doses of I.V. narcotic is given in the immediate postoperative period. By that evening or the following morning most patients are comfortable on oral codeine or acetaminophen. It is very important, especially in the patients with compromised lung function, to start early and aggressive pulmonary toilet. The significant decrease in postoperative pain associated with a thoracoscopic approach results in much less splinting and allows for more effective deep breathing. This has resulted in a decrease in postoperative pneumonias and other pulmonary complications.

Conclusions

The recent advances in technology and technique in endoscopic surgery have dramatically altered the approach to intrathoracic lesions in the pediatric patient. Most operations can now be performed using a VATS approach with a marked decrease in the associated morbidity for the patient. This has allowed for an aggressive

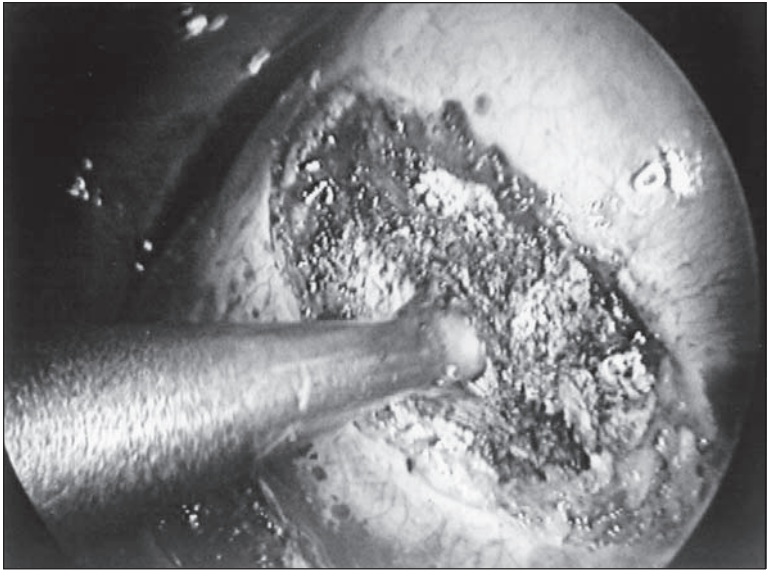


Figure 24.14. A thoroscopic discectomy being performed with a modified curette. The disc space will then be filled with bone graft to enhance fusion.

approach in obtaining tissue for diagnostic purposes in cases of ILD or questionable focal lesions in immunocompromised patients without the fear of significant pulmonary complications previously associated with a standard thoracotomy. In general, a lung biopsy can now be performed with little more morbidity than a transbronchial biopsy yet the tissue obtained is far superior. The same is true for mediastinal masses or foregut abnormalities. Patients undergoing limited biopsy can now be done as same day surgery and lesions such as esophageal duplications can be excised thoroscopically with the patient ready for discharged the following day. Even patent ductus arteriosus closures are now performed safely thoroscopically with a hospitalization of less than 24 h. And while a thoroscopic approach may not always result in a significant decrease in hospital days it may result in a significant decrease in the overall morbidity for the patient. Such as in the case of severe scoliosis patients in whom a thoroscopic anterior spinal fusion results in earlier extubation, a decreased intensive care unit stay, and in general earlier mobilization. Thoroscopic surgery has clearly shown significant benefits over standard open thoracotomy in many cases and with continued improvement and miniaturization of the equipment the procedures we can perform and the advantages to the patient should continue to grow.

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Video-Assisted Repair of Diaphragmatic Defects

Marcelo Martínez Ferro

Introduction

Surgical procedures are frequently performed on the diaphragm in children. The diseases associated with this organ may be either congenital or acquired:

<i>Congenital</i>	Bochdalek Posterolateral Diaphragmatic Hernia and its Variants Morgagni Anterior Hernia Paraesophageal Hernia Congenital Eventration of the Diaphragm
<i>Acquired</i>	Phrenic Nerve Paralysis Traumatic Rupture

The development of video-assisted surgery brought about a significant change in the surgical repair of these diaphragmatic conditions. Although to date there is little clinical experience available, in the near future most diaphragm-related problems will be amenable to laparoscopic or thoracoscopic repair.

This chapter will concentrate on the approach to diaphragmatic defects through the use of these minimally invasive techniques.

Bochdalek Posterolateral Diaphragmatic Hernia and its Variants

Background and Development of Surgical Techniques

Although in 1848 Vincent Bochdalek, an anatomist, described two cases of diaphragmatic hernia, it was in 1902 that Heidenhaim first successfully repaired a diaphragmatic hernia in a 9-year-old child.

Thirty-eight years later, Ladd and Gross successfully performed surgical operation of the defect in a 40-hour-old infant.

This was followed by an increase in survival until the 1960s and 1970s when, despite the fast development of neonatal intensive care units, an increase in mortality was observed. Improvement in prenatal diagnostic techniques—with particular emphasis on sonography—served to emphasize this observation.

The medical community slowly came to the conclusion that what seemed to be a simple anatomical defect, able to be surgically repaired, represented a complex embryological pathophysiology resulting in bilateral pulmonary hypoplasia with pulmonary hypertension.

The concept of hidden mortality described in 1978¹ revealed that, in fact, the number of patients dying of this pathology was significantly higher than that observed in major referral centers, given that many patients died before birth or in the immediate perinatal period, and many of them died untreated.

Successful techniques such as high-frequency ventilation, nitric oxide and extracorporeal membrane oxygenation (ECMO), which were implemented throughout the years for the treatment of severely affected neonates, failed to decrease the rate of mortality of this serious malformation that is currently observed in 50% of the affected cases.

Surgical techniques are divided into those designed to repair the defect before birth through fetal surgery and postnatal techniques.

Fetal surgery for the treatment of diaphragmatic hernia, first implemented by Harrison,² has significantly developed in the last decades. The original surgery, which consisted in repairing the defect in the fetus just as it is corrected in the newborn, has been abandoned because it proved ineffective. To date, the defect is treated with a detachable silicon balloon that allows fetoscopic obstruction of the fetal airway.³ This obstruction results in bilateral lung growth in contraposition to the effect of hypoplasia and arterial hypertension. This surgery is only performed in cases with a fatal prognosis, and its efficacy needs to be further demonstrated by adequate randomized studies.

Postnatal techniques, on the other hand, remained basically unchanged from the 1950s to the advent of minimally invasive surgery.

In 1995 van der Zee described the laparoscopic surgical repair of a congenital posterolateral hernia in a six-month-old infant.⁴ Thereafter, video-assisted repair has become the method of choice for non-severely affected patients in those centers highly specialized in these techniques.

Patient Selection for Minimally Invasive Surgery

Video-assisted repair should be performed only in patients with no sign of pulmonary hypertension, who are hemodynamically stable.

Candidates for video-assisted diaphragmatic repair:

- Newborns requiring oxygen administered through nasal route
- Newborns on mechanical ventilation with minimal or decreasing parameters

Infants or children with a late diagnosis of congenital diaphragmatic hernia (CDH)

At least 48 h of hemodynamic stability in the absence of pulmonary hypertension is required in all cases.

Figures 25.1 and 25.2 show respectively the pre- and postoperative chest x-rays of a newborn with a diaphragmatic hernia. Meeting the above selection criteria, the newborn underwent laparoscopic surgery at 48 hours after birth. Most patients with CDH are not candidates for repair with minimally invasive techniques.

Surgical Technique

Diaphragmatic defects may be approached either through the thorax⁵ or the abdomen,⁴ this choice depending on the expertise and preference of the surgeon. Supporters of the thoracoscopic route point out that abdominal viscera are easily reduced with the CO₂ insufflated into the thorax.^{6,7} Supporters of the laparoscopic

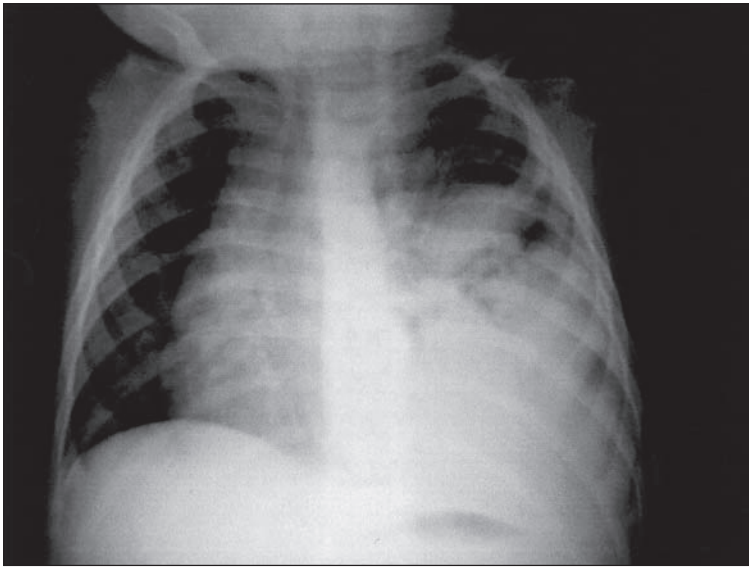


Figure 25.1. Posterior-anterior chest x-ray of a 48-hour-old newborn with left congenital diaphragmatic hernia. The patient is stable with no signs of pulmonary hypertension.

approach refer to easier manipulation of the instruments and the ability to visualize the reduced viscera, thus avoiding unnoticed lesions.⁸

Thoracoscopic Technique

This type of approach requires placement of two 3 mm trocars and one 5 mm trocar, as shown in Figure 25.3.

Insufflation of CO₂ from the thorax allows good visualization of the defect and contributes to the reduction of the viscera in the abdomen. The presence of a hypoplastic lung facilitates the procedure and makes selective intubation unnecessary.

In the presence of a sac, reduction is easier and the diaphragmatic defect is gradually corrected as the sac is resected. In order to facilitate suture of both diaphragmatic edges, traction sutures are placed on the posterior edge and traction is held from outside.

Knots are tied using either intracorporeal or extracorporeal technique. We prefer the latter due to the lack of space for maneuvering in these children.

Upon diaphragmatic repair completion, pleural drainage—if necessary—is inserted through one of the trocar sites.

Laparoscopic Technique

This technique requires placement of three trocars and a 2 mm palpation probe, as illustrated in Figure 25.4. The first trocar is placed in the umbilicus and serves to introduce a 3 mm 30° telescope. The two additional trocars, 3 mm and 5 mm respectively, are used for the surgical repair. The palpation probe is placed directly,

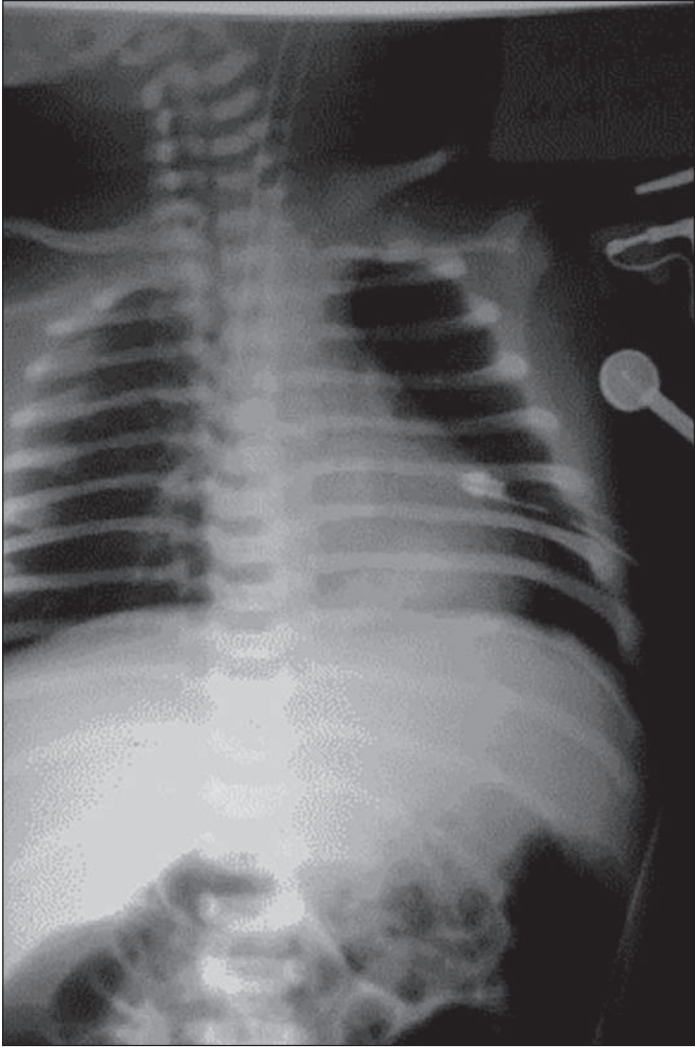


Figure 25.2. Immediate postoperative x-ray following laparoscopic repair of the diaphragmatic defect in the above mentioned patient.

through a stab wound with no trocar, because there is no need to replace it as it is used to retract the liver, hold the upper edge of the diaphragm and hold the reduced viscera (e.g., spleen, intestine, stomach) in the abdomen. Insertion of the needle holder is performed using a 5 mm trocar that allows easy insertion of a curved needle.

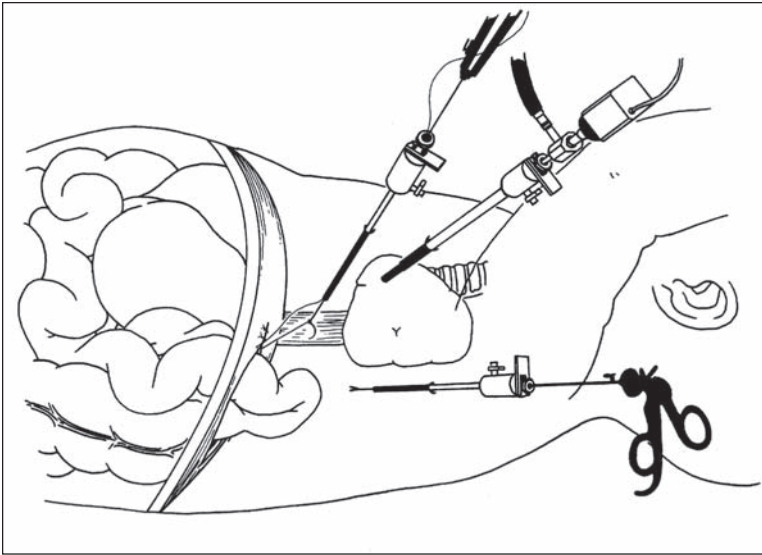


Figure 25.3. Description of the thoracoscopic technique for the repair of Bochdalek left hernia. Insufflation of CO_2 into the thorax facilitates the reduction of viscera in the abdomen.

Insufflation pressure varies between 5 and 8 mm Hg depending on the newborn is tolerance to this maneuver. Low pressures are well tolerated.

In the presence of a sac, resection is the first maneuver. Resection is performed exerting traction from the bottom of the sac and everting it toward the abdomen. Then, the sac is opened and resected, preserving only the diaphragmatic edge for closure.

A small hernia requires the use of the palpation probe to keep it open and reduce the viscera in the abdomen, as shown in Figure 25.5. Insertion of the telescope through the defect is useful to inspect the size and characteristics of the hypoplastic lung.

After reduction of the contents, the diaphragmatic repair is performed with non-absorbable sutures such as Ethibond 3/0 with RB-1 needle (see Fig. 25.4). The needle and the suture are inserted through the 5 mm port and the knot is tied from outside using a Roeder loop (Fig. 25.6) that is advanced with the 3 mm needle holder.

Occasionally, it is convenient to place one or two traction sutures on the posterior edge of the diaphragm. These sutures are inserted through the abdominal wall and diaphragm, and exit back out through the abdominal wall (Fig. 25.7).

This technique allows continuous visualization of the viscera reduced in the abdomen, thus avoiding unnoticed injuries when suturing the defect. Placement of a pleural drainage will depend on the local practice. In our particular case, a pleural drainage is always used in patients with diaphragmatic hernia, as illustrated in Figure 25.2.

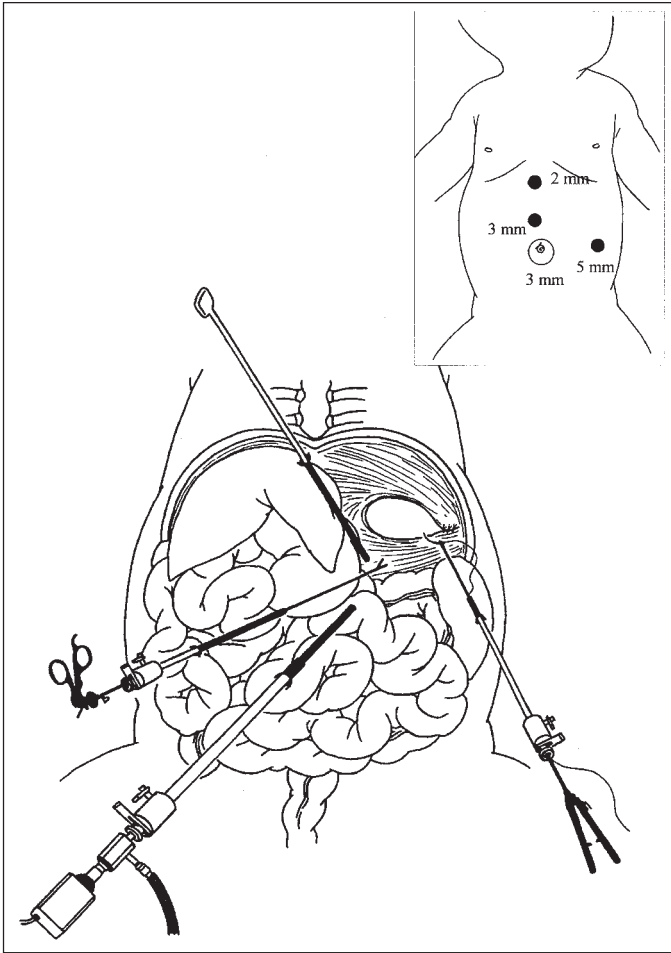


Figure 25.4. Description of the technique used for laparoscopic repair of Bochdalek left hernia with four trocars (see the above description). The palpation probe placed in the epigastrium can be introduced directly, with no trocar.

Results

The postoperative course of patients with CDH is highly dependent on the patient's preoperative condition. Thus, patients on mechanical ventilation in the preoperative period are expected to remain the same for 24 to 48 hours postoperatively.

On the other hand, children who are asymptomatic or have no respiratory symptoms are the best candidates for this minimally invasive technique. They make an immediate postoperative recovery, with significant amelioration of the postoperative pain and early feeding. Some of these patients are discharged 24 hours postoperatively.

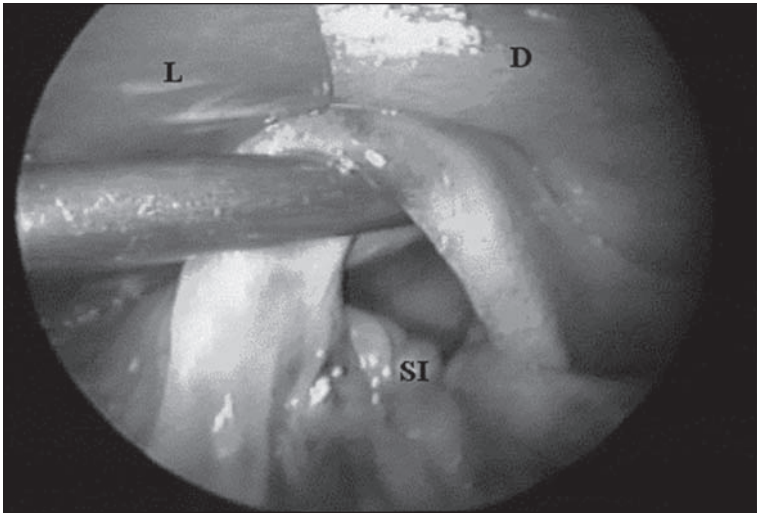


Figure 25.5. Endoscopic visualization of Bochdalek left hernia in a newborn. The palpation probe holds the edge of the diaphragm and facilitates intestinal reduction to the abdomen.

Furthermore, aesthetic results have proved to be favorable and better than those obtained with the conservative technique, as shown in Figure 25.8.

Since these techniques have been recently developed, there are no data available yet on long term follow-up. However, no significant differences with regard to open surgery can be expected, given that repair of the diaphragm is similar and uses the same material.

Morgagni Retrosternal Hernia

Embryology and Incidence

Morgagni hernia, also known as retrosternal or parasternal hernia, is located anterolaterally in the area embryologically belonging to the junction between the septum transversum and the chest wall. This condition occurs similarly on the right and left side. It generally presents with a sac containing part of the transverse colon, small intestine or liver. Cantrell's pentalogy presents with a larger retrosternal diaphragmatic defect. However, we will not address on this syndrome here.

Morgagni hernia is unusual, accounting for 1 to 2% of all the congenital diaphragmatic defects.

A large variety of associated malformations have been described, with congenital cardiopathies and trisomy 18 being the most frequently observed. These associated malformations should be ruled out before surgical repair of the defect.

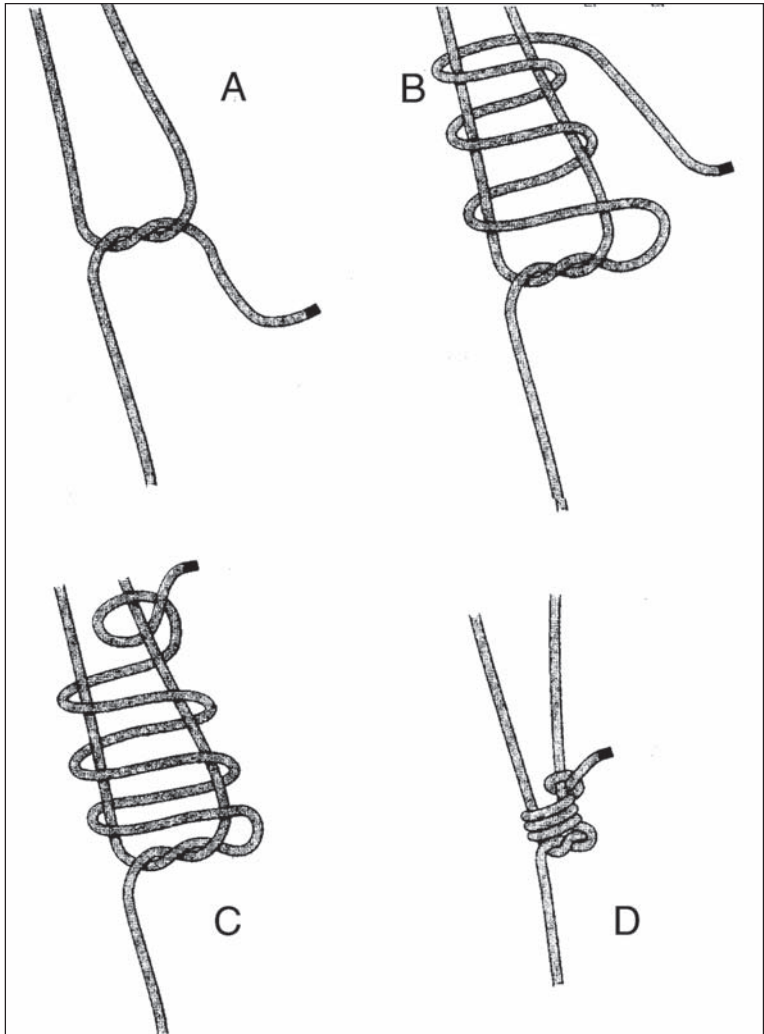


Figure 25.6. Roeder knot used for all diaphragmatic surgeries.

Symptoms and Diagnosis

Most patients with a Morgagni hernia are asymptomatic and their condition is frequently diagnosed on an individual casual basis after routine chest x-ray. Morgagni retrosternal hernia is rarely associated with nonspecific respiratory symptoms or gastrointestinal signs such as vomiting or epigastric pain.

This entity generally manifests after the neonatal period, in older children and adolescents. Diagnosis is made with posterior-anterior and lateral thoracoabdominal

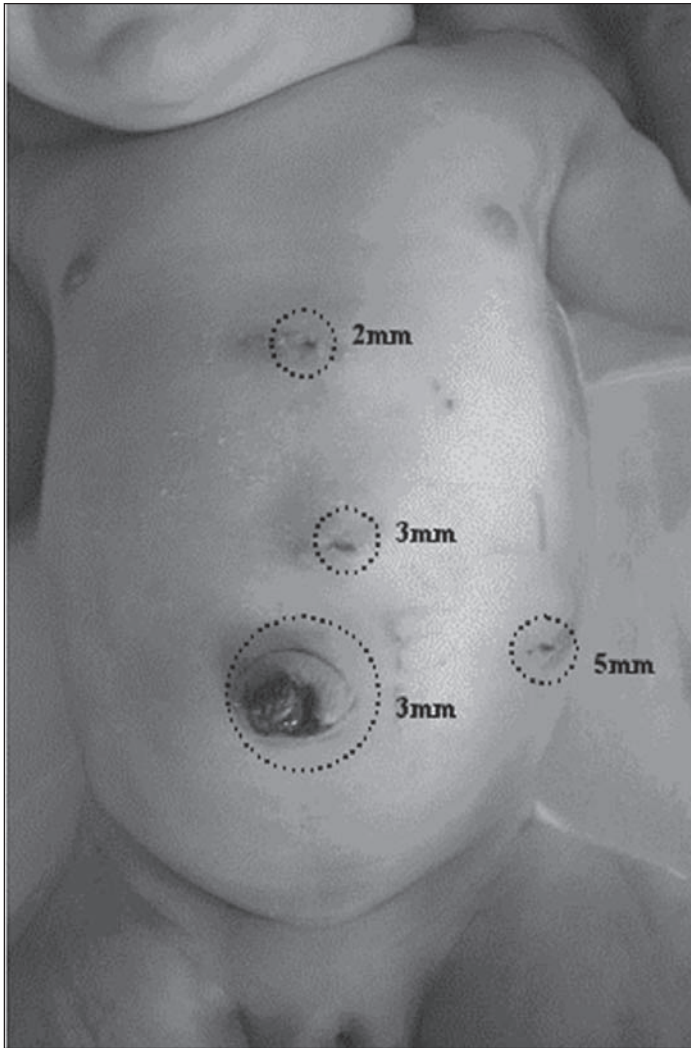


Figure 25.7. Early postoperative period of a newborn who underwent surgery due to left diaphragmatic hernia. Note placement of the external traction suture used to raise the lower edge of the diaphragm and trocar localization.

radiography and is confirmed by contrast gastrointestinal study with the patient in the lateral and oblique position. Sonography may confirm or rule out the presence of liver within the defect. On certain occasions, the diagnosis has been made during laparotomy or laparoscopy for other reasons.⁹



Figure 25.8. Three months postoperative follow-up of the patient described in Figure 25.7.

Laparoscopic Surgical Treatment

Surgical treatment using video-assisted techniques has been already described by several authors who all agree on the abdominal—rather than the thoracic approach.¹⁰⁻¹²

Laparoscopic repair of retrosternal diaphragmatic defects requires the use of three trocars, as illustrated in Figure 25.9.

The development of this operation does not differ from that of open surgery, which consists of reduction of sac contents, resection of the sac and closure of the

defect using interrupted non-absorbable sutures. Ethibond 2/0 or 3/0, depending on the age of the child, is preferred. For large defects, a synthetic prosthesis can be placed as in open surgery, by inserting the prosthesis into a 10 mm trocar that will replace the previously inserted 5 mm trocar.

Since the 5 mm trocar will be used to insert the needle holder with its needle, it is advisable to place it on the right side. Non-absorbable suture, such as the Ethibond 3/0 with RB-1 needle or the 2/0 with SH needle, is preferred. Extracorporeal knots are used, which are advanced with the knot pusher or needle holder. A Roeder knot slid down with the needle holder was used throughout the diaphragmatic surgery (Fig. 25.6). Although pleural drainage is unnecessary, the surgeon should monitor the patient for the development of pneumothorax after surgery.

Results

Optimal surgical, functional and aesthetic results have been obtained from the laparoscopic treatment of retrosternal defects. Prompt recovery allowed early feeding 2-3 h after surgery and discharge at 24 hours.

Paraesophageal Hernia

Embryology and Incidence

Paraesophageal defects are extremely rare and are caused by a defect of fusion of periesophageal mesoderm and the right pleuroperitoneal membrane. They account for less than 1% of all the diaphragmatic defects in childhood.

Symptoms and Diagnosis

Patients with a paraesophageal hernia are generally asymptomatic and their condition is frequently diagnosed incidentally after a routine chest x-ray in adolescence or adulthood. Some patients, however, present with nonspecific gastrointestinal symptoms such as vomiting or epigastric pain. Although the stomach is in an abnormal position, gastroesophageal reflux is not frequently observed in these patients. Obstruction and strangulation of the intrathoracic part of the stomach have been reported and can be avoided with surgical repair. Diagnosis can be suspected when a chest x-ray reveals a left paracardiac air fluid level. Diagnosis is confirmed by a contrast gastroesophageal study, as shown in Figure 25.10. Preoperative pH probe study is advisable.

Surgical Treatment

For this problem, laparoscopic surgical repair requires the same set-up as for a laparoscopic Nissen. Therefore, four trocars are placed as shown in Figure 25.11. After the stomach is reduced and the sac treated, the defect is closed using interrupted non-absorbable sutures, such as 3/0 Ethibond. Performance of an antireflux wrap depends on the presence or absence of reflux, confirmed by preoperative pH probe study. Routine antireflux procedures are not performed in the absence of demonstrated gastroesophageal reflux.

Results

After repair of the defect, recurrence is rare even in patients with associated gastroesophageal reflux. A favorable response to surgical treatment usually is observed.

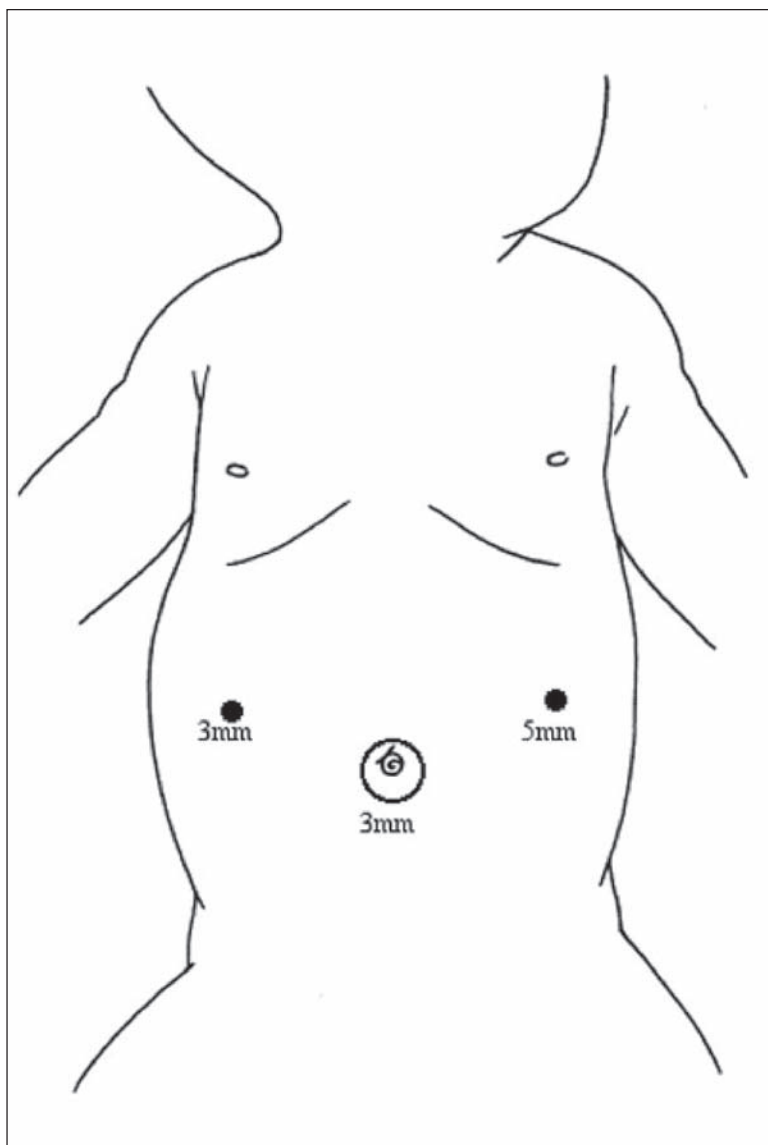


Figure 25.9. Trocar placement, used for laparoscopic repair of Morgagni defect.

Congenital Eventration of the Diaphragm

Embryology and Description

Although the term “congenital eventration of the diaphragm” includes a wide variety of phrenic nerve injuries, we will now refer only to those patients who present diaphragmatic flaccidity since birth, with no history of obstetrical trauma. This congenital condition is not easily differentiated from a diaphragmatic hernia with a sac or from a post-traumatic phrenic nerve paralysis.

Congenital eventration of the diaphragm is of unknown origin but may be associated with intrauterine phrenic nerve injury due to stretching or aplasia. Another hypothesis is the lack of migration or development of muscular cells in the affected areas. Macroscopically, we observe partial defects or “bulging” in the surface of the diaphragm, or total stretching or attenuation of this organ. The right side is more frequently affected than the left, with the anterior portion of the diaphragm being, in general, the most affected.

Histologically, and unlike the diaphragmatic hernia with sac, eventration contains striated muscle cells in the whole defect. The diaphragmatic muscle has a normal distribution, but is extremely thin and inactive.

Symptoms and Diagnosis

According to the size of the eventration, patients may be asymptomatic or present with symptoms even in the immediate neonatal period. In neonates, mechanical ventilation is sometimes required due to fatigue resulting from their weak intercostal musculature.

In older children, several different manifestations can be observed, including intolerance to exercise, chronic respiratory distress, pneumonia and recurrent airway obstruction.

Diagnosis is made with posterior-anterior and lateral chest x-rays. The posterior-anterior x-ray shows the affected side and the lateral x-ray demonstrates which portion of the diaphragm is affected (Figs. 25.12 and 25.13).

In case of an uncertain diagnosis, a dynamic fluoroscopic study will show an absence of diaphragmatic movement and paradoxical movement of the contralateral diaphragm.

Ultrasound further facilitates the diagnosis, especially when transport to the radiology suite is not advisable.

Laparoscopic Surgical Treatment

Surgery is limited to symptomatic patients, given that on several occasions partial eventration of the diaphragm is incidentally diagnosed after a routine chest x-ray.

These defects were originally approached through the abdomen or the thorax, depending on their left or right location, respectively. Minimally invasive video-assisted techniques allowed successful approach to both diaphragms through the abdomen. Although few data have been reported on this procedure in children, there is general consensus that laparoscopy is the method of choice.^{13,14}

In order to repair the defect, plication of the diaphragm with several rows of anteroposterior sutures is performed, as illustrated in Figure 25.14. This technique has been long performed through the conventional open route for the treatment of

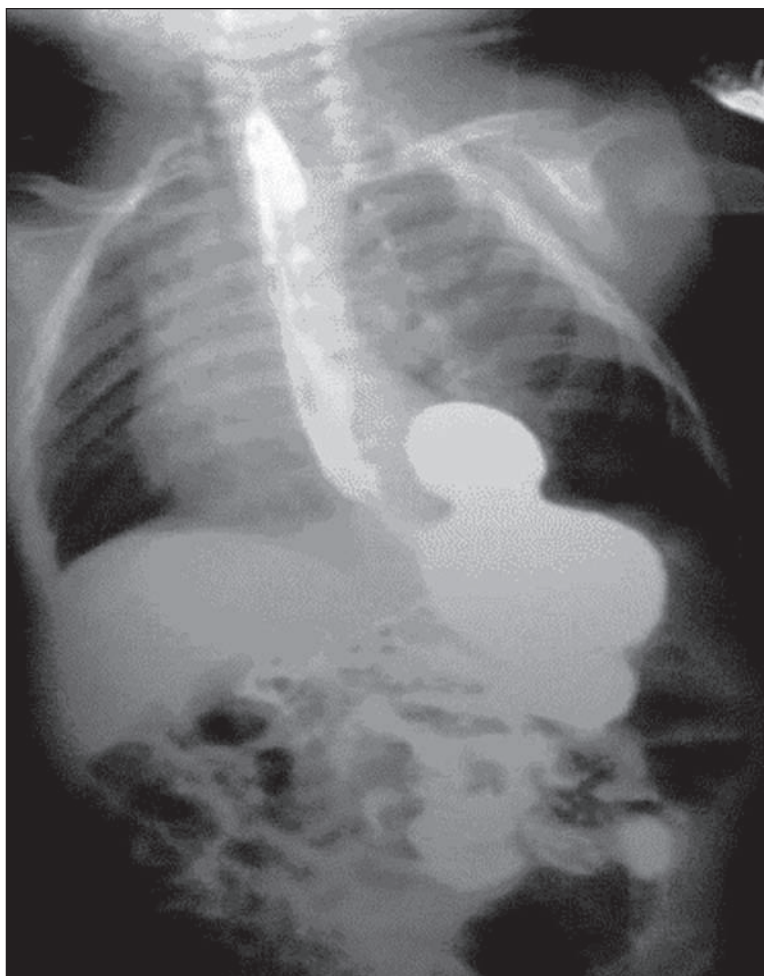


Figure 25.10. Barium swallow study showing paraesophageal hernia in an infant. This patient presented no gastroesophageal reflux.

eventration and phrenic nerve paralysis. Plication increases tidal volume and maximal breathing capacity.

Laparoscopic repair is performed using three to four trocars, as shown in Figure 25.14. Trocars should be placed in such a way to allow full visualization of the diaphragm. Right defects usually require a 2 mm palpation probe placed at the epigastrium. This instrument may be inserted with no trocar and serves to separate the right lobule of the liver from the surgical field (Fig. 25.14).

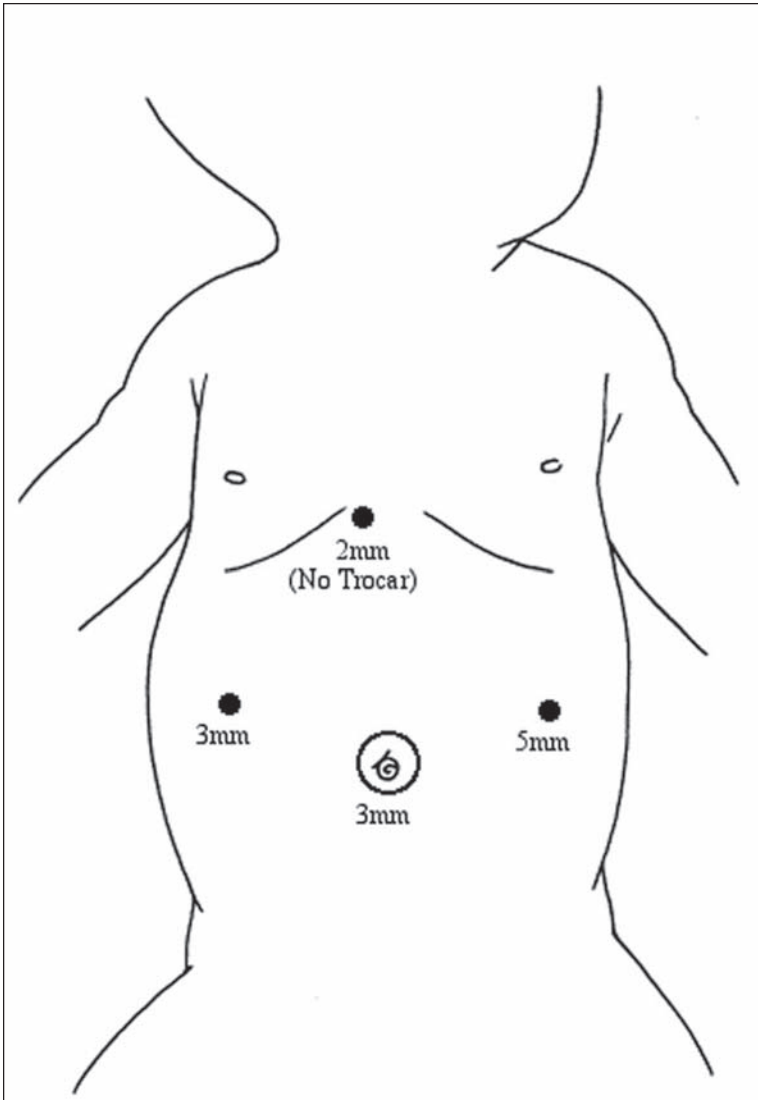


Figure 25.11. Trocars placement for surgical repair of a paraesophageal hernia.

Plication through the abdomen necessarily requires a maneuver known as “Provoked Controlled Pneumothorax” (PCP), which consists in injecting air into the pleural space ipsilateral to the defect with a syringe and a plastic trocar (Figure 25.14). Air injection causes diaphragmatic bulging and facilitates plication, with no risk of

unnoticed pulmonary injury when suturing. The volume of air injected depends on the size of the patient and on his tolerance for the procedure. Although the maneuver was well tolerated, it should be performed slowly and controlled together with the anesthesia.

Anteroposterior sutures are used and each row is tied separately, as illustrated in Figure 25.15. Nonabsorbable suture such as Ethibond 3/0 with RB-1 needle or 2/0 with SH needle is used, depending on the size of the patient. The suture is tied from outside with a Roeder knot, which is advanced with the 3 mm needle holder (Fig. 25.6).

Following plication, the pneumothorax is evacuated with the plastic trocar under water seal and the procedure is monitored with intraoperative fluoroscopy. Pleural drainage tubes are always removed when the air is evacuated (Fig. 25.16).

Results

This surgical procedure is well tolerated and, as it has been observed in the open technique, respiratory symptoms resolve immediately and preoperative signs disappear.

After laparoscopic plication, feeding is resumed 2-3 h postoperatively and patients are discharged before 24 h, except for those who were on mechanical ventilation before surgery. In these patients, gradual weaning is indicated and they are likely to be discharged between 48 and 72 h postoperatively.

As in all laparoscopic procedures performed with 3 mm instruments, optimal aesthetic results are obtained.

Given that laparoscopic surgery has been recently described, no data exist about long-term results. However, results should not differ from those obtained with open surgery since this is the same procedure, using the same suture and only differing in the approach.

Phrenic Nerve Paralysis

Etiology and Pathophysiology

Phrenic nerve paralysis in childhood generally occurs due to two different causes.

Birth trauma in the newborn results from stretching or avulsion of the fourth and fifth cervical roots which form the phrenic nerve. This complication occurs after dystocia and/or forceps delivery, and in approximately 75% of the cases it is associated with brachial paralysis or ipsilateral fracture of the clavicle. Most injuries are unilateral. Bilateral diaphragmatic paralysis is rare.

Iatrogenic causes after cardiovascular surgery can be detrimental to children undergoing congenital heart surgery. The surgeon should be aware of this complication in order to perform the appropriate surgical treatment.

In the absence of serious lesions, partial or complete recovery of diaphragmatic movement has been observed. The time required to confirm this circumstance is controversial, but most authors agree that plication of the diaphragm should be performed after 3 to 4 weeks.

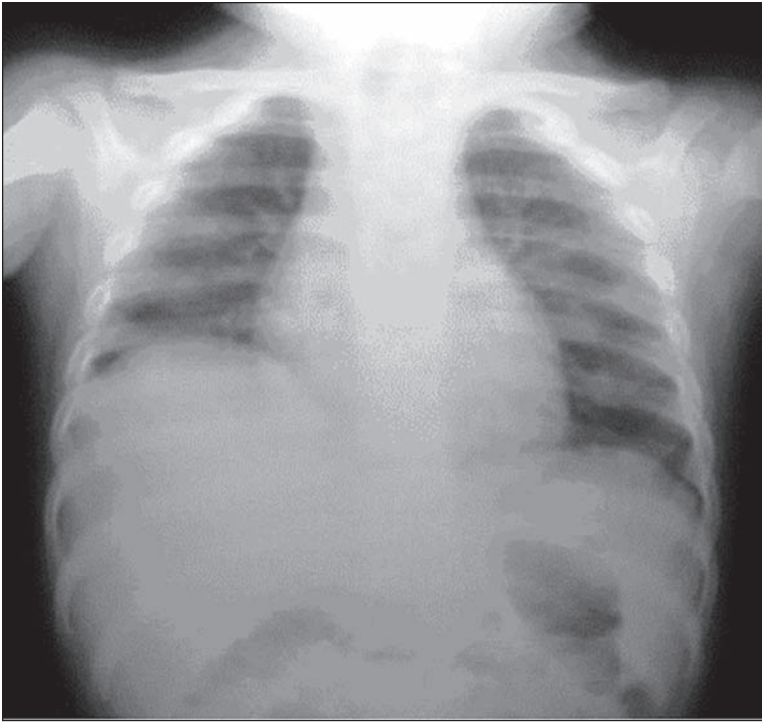


Figure 25.12. Posterior-anterior chest x-ray showing right eventration of the diaphragm.

Diagnosis, Treatment and Evolution

Except for etiologic background, this entity cannot be easily differentiated from the abovementioned eventration of the diaphragm. Therefore, both the clinical condition and the treatment are the same.

The same postoperative course is expected except that most of these children are on mechanical ventilation in the preoperative period, and they are therefore discharged later than those with pure eventrations of the diaphragm.

Acknowledgements

The author wants to thank Dr. Gabriela Duarte for her assistance in the preparation of this chapter, and Ignacio Rodríguez for the figures.

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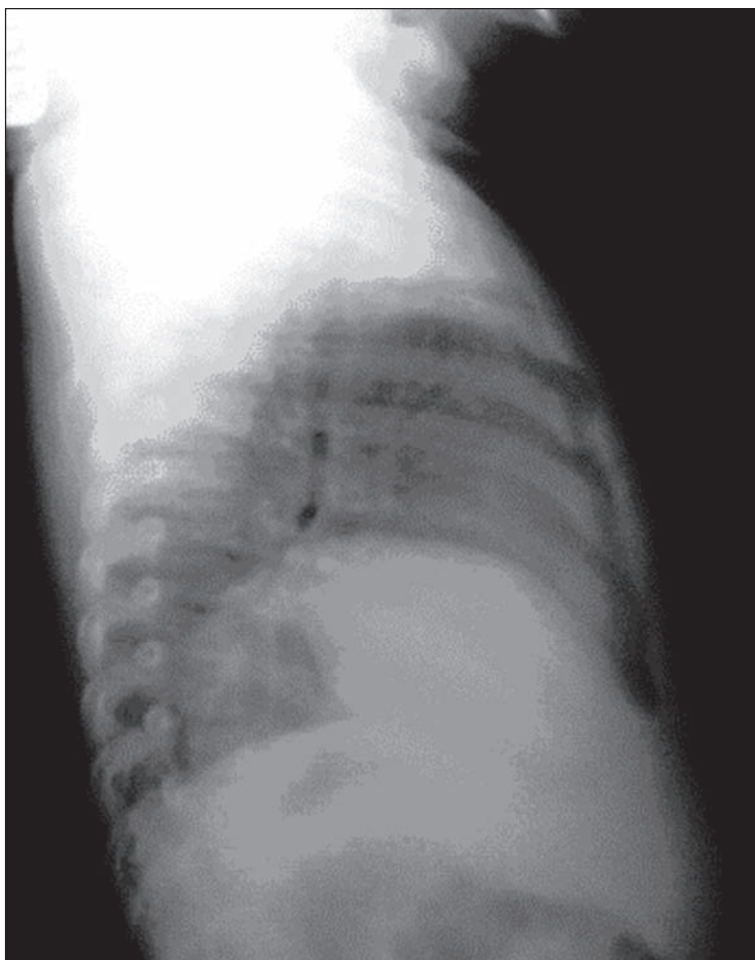


Figure 25.13. Lateral chest x-ray of the patient described in Figure 25.12.

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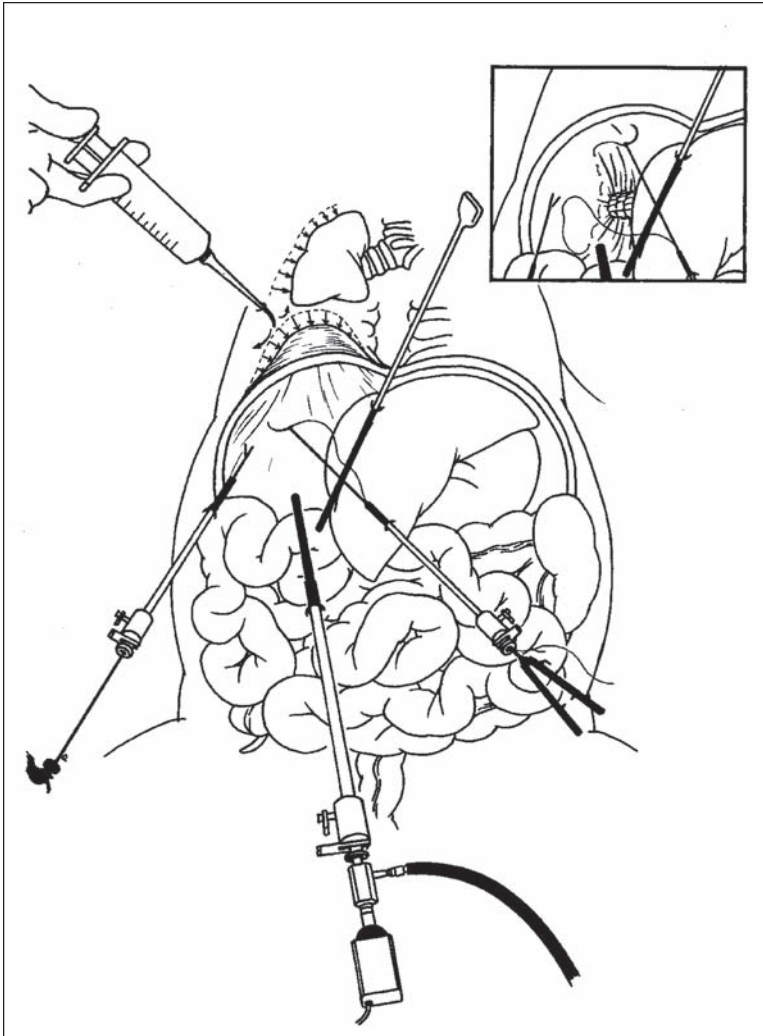
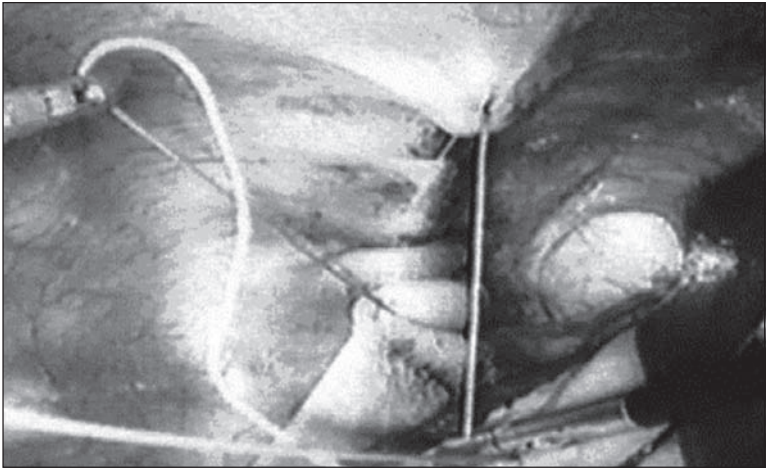


Figure 25.14. Depiction of the technique used for laparoscopic plication of the diaphragm. In order to facilitate diaphragmatic suture, air is injected into the thorax, thus producing controlled temporary pneumothorax. Pneumothorax is evacuated before surgery completion and is controlled by radioscopy. The top inset shows the result of plication of the diaphragm. The palpation probe placed in the epigastrium can be inserted directly, with no trocars.



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Figure 25.15. Intraoperative visualization of plication of the right diaphragm. The traction exerted by the needle holder and the grasper on the suture allows determining the effect of the plication on the diaphragmatic curvature.

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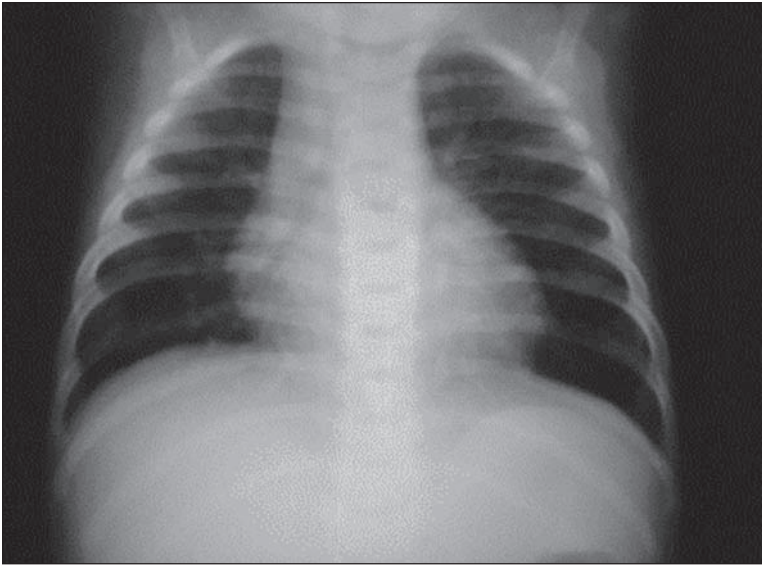


Figure 25.16. Immediate postoperative x-ray of the patient described in Figures 25.12 and 25.13, who underwent laparoscopic right diaphragmatic plication. No chest tube is left after surgery completion.

Endoscopic Parathyroidectomy in Children

Olivier Reinberg

Introduction

Since the beginning of the 1990s endoscopic minimally invasive techniques have been applied for surgery of the thorax and the abdomen of children, both areas being natural cavities to work in. The pediatric surgeon has had to be trained to work in narrow spaces. With the improvement of technical skills in endoscopic surgery and the development of thinner and shorter instruments, new spaces have become accessible to endoscopic surgery. The creation of operating fields in virtual spaces by pneumodissection, as for example in the retroperitoneum, has also become possible.

In 1997, at the first course of endocrine endosurgery of the European Institute of Tele-Surgery (EITS) in Strasbourg, France, Gagner, Marescaux et al applied their technique performing endoscopic neck operations on animals and human patients, also describing the potential hazards and measures to avoid them.

Thoracoscopic resection of mediastinal parathyroid adenoma has been described in several reports. In 1996, Gagner published the first case of subtotal resection of the parathyroids via a cervical endoscopic approach in a 37-year-old man. The operation lasted 5 hours, and the only problems incurred were the development of hypercarbia and tachycardia. Other such experiences have been reported, either in experiments or in human adults. In 1997, Hüscher et al reported their first endoscopic right thyroid lobectomy for a 4 mm sized adenoma, and in 1998 Yeung reported his experience of three endoscopic parathyroidectomies for adenomas and five endoscopic hemithyroidectomies which were carried out without any complications.

These preliminary experiences brought evidence that endoscopic dissection and surgical intervention of the neck were safe and technically feasible options. Based on our former experience in creating a working space in the neck and in the mediastinum by performing video-assisted thymectomies in children, pure endoscopic thyroid and parathyroid dissection have now become feasible.

Surgical Technique

Under general anesthesia, the patient is placed in a supine position with the neck slightly hyperextended, but however less than in the conventional position for open surgery, as mentioned by Gagner. The end-tidal airway pressure of CO₂ (P_{ET}CO₂) has to be monitored with special care, to be lowered by adjustment of the tidal volume and ventilation frequency if needed. (Fig. 26.1)

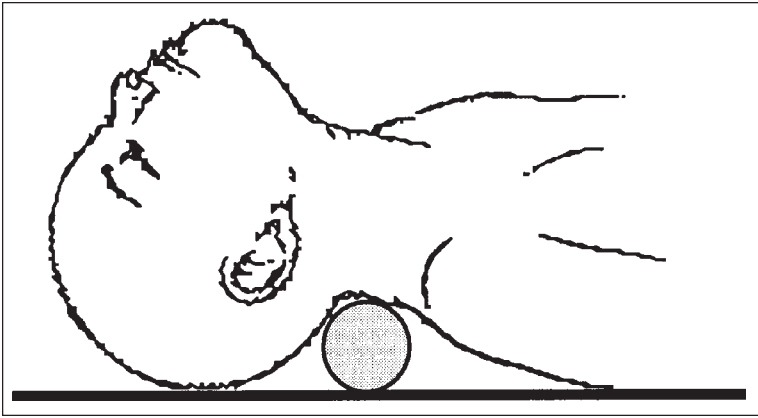


Figure 26.1. Position of the patient.

A 10 mm transversel incision is made just above the suprasternal notch. An open dissection is performed through the platysma and then, deeper inside, through the fascia of the neck between the anterior borders of the sternohyoid muscles down to the pretracheal space. The midline venous structures have to be avoided, or ligated and divided if necessary, to prevent any bleeding (Fig. 26.2).

A 5 mm x 45° trocar (Aesculap Promis Line) is inserted into the surgical wound under direct vision. A pursestring suture taking in the platysma layer and the skin, can be tied around the trocar to achieve an airtight seal and to prevent the trocar from slipping out of the wound. A 4 mm x 25° x 170mm telescope (Panoview Plus Wolf) is set up and CO₂ insufflation at a pressure of 12 mm Hg can be started to produce the initial surgical emphysema. Subsequently, it can be decreased to 6-8 mm Hg once the space has been developed. Pneumodissection separates the soft prethyroidal fascia and lifts the anterior cervical muscles away from the thyroid, thus developing a surgical space in which to work. Pneumodissection is helped by the gentle motion of the optical system. The surgeon has to be patient as this step of the procedure takes a few minutes.

Once enough space has been created, two 3 mm short reusable Teflon ports for instruments are inserted under view control through the sternomastoid muscle, 3 cm on each side of the median line, thus avoiding any damage being caused to the internal jugular veins. The use of reusable Teflon ports is advantageous because they are light. Short pediatric 3 mm atraumatic instruments (18 cm) are passed through them. Gentle back and forth movements help spread the pneumodissection and widen the space for the operation. A 3 mm monopolar hook, or scissors, is used to cut some firm fibers which fix the soft fascia. Crossing veins are coagulated with a 3 mm bipolar cautery (all instruments and ports by Micro-France). The dissection needs to be bloodless to allow optimal view.

When an adequate working space has been acquired, the insufflating pressure of the CO₂ is reduced to 6-8 mm Hg and dissection of the thyroid gland can then be performed. Its lower poles and inferior vascular bundles are first identified.

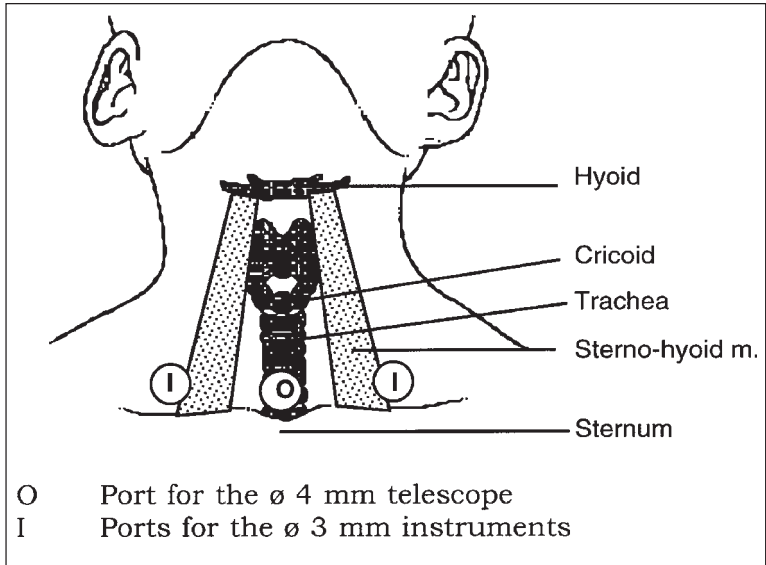


Figure 26.2. Position of the ports.

Pneumodissection removes the need to search for the recurrent nerves which can easily be visualized.

The first stage of the intervention focuses on one lobe of the thyroid, for instance the left one. A 3 mm Babcock forceps is inserted from the right hand side as a retractor while the gland is dissected with a smooth 3 mm bipolar cautery inserted from the left port. The magnification of the operating field allows a very good view of the different tissues. An excellent lateral view of the thyroid can be achieved by rotation of the 25° telescope, as well as a view from underneath. The lateral edges of the thyroid gland can be elevated without dividing the thyroid pedicles. In comparison with the open technique, the endoscopic procedure facilitates the task of locating the parathyroids, as the latter appear as a buff-coloured gland against the pink thyroid in a bloodless field. Once a parathyroid is identified, it is gently enucleated from its bed and, after bipolar coagulation its vessels divided. Then the parathyroid can be released from the thyroid, and removed. We use a finger tip glove inserted through a trocar hole to place the gland inside it. The open end of the finger tip is firmly held in the trocar, then the trocar and the bag are gently removed en bloc using circular movements.

Then the opposite side is dissected. The trocar is repositioned in order that the other parathyroids could be removed in the same way. Each parathyroid is histologically examined after removal to confirm that its entirety has been taken out.

At the end of the procedure, the instrument ports are removed under visual control so that any bleeding can be observed while the working space is being deflated. No drainage is required as no bleeding should remain after exsufflation. The

median muscles are drawn together by a running resorbable suture through the suprasternal incision and the wounds are closed with 5-0 monofilament nonresorbable sutures.

Postoperative Course

There should not be peri- or postoperative hypercapnia. Some postoperative emphysema can be observed, and this disappeared completely within 24 hours.

Postoperative pain can easily be controlled with paracetamol and mefenamic acid.

Once the level of calcium has been stabilized, on the third postoperative day, the patient can be discharged.

We have carried out such a procedure in two cases:

The first one was a 14 year-old male suffering from end stage chronic renal failure with progressive osteodystrophy and uncontrolled hypercalcemia. He underwent an endoscopic total parathyroidectomy in July 1998. To our knowledge this type of intervention has not been previously reported in a child.

The second one was a 8 year-old boy with a hyperparathyroidism related to an adenoma located in the left lower lobe of the thyroid as a 15 mm nodule, which was resected by a total endoscopic approach.

Our patients suffered no postoperative complications. There was no evidence of laryngeal nerve injury. We recorded no intra- or postoperative hypercapnia. Emphysema was mild and disappeared within 24 h in both patients. Paracetamol and mefenamic acid were required until the second postoperative day. Three days postoperatively the level of calcium was stabilized in both patients and patients discharged on day 3 and 4.

The total removal of the cervical parathyroid glands in the first case was followed by an autotransplantation of one of the parathyroids into the forearm. Thus the entire operation lasted 3 hours 27 min. In the second case it lasted 2 hours 10 min.

Discussion

Parathyroidectomy is one of the most commonly performed endocrine procedures and as its technique is well known, it is considered to be a relatively safe procedure.

However iatrogenic injuries of the laryngeal nerve are not uncommon: there is a 0.5 to 3 % chance of nerve paralysis occurring, even for experienced surgical teams. Early visualization and dissection of this nerve are considered mandatory for its preservation. Anatomical variations are well known and may be the cause of accidental truncation of the laryngeal nerve.

Several attempts to facilitate the surgical approach and to minimize the hazards of dissection have been described: localization of the lesion by technetium-99m methoxy isobutyl isonitrile imaging (Tc-99m MIBI = Sestamibi scan) or by MRI; percutaneous preoperative needle localization of the parathyroid; minimal bilateral access. However, reoperation for recurrent hyperparathyroidism is not uncommon, and may become necessary in 3 to 10% of cases. Theoretically the risk of reoperation being required is therefore higher with minimal access procedures as these do not allow extensive exploration of the operating field.

Endoscopic surgery of the neck gives the theoretical advantage of overcoming these problems. Perhaps the most important benefit, which was recognized in both

the laboratory and the operating theater, is that the telescope and video monitor allow precise anatomic details to be seen. This extended microsurgical view prevents damage being inflicted on the surrounding vascular or nervous structures, the laryngeal nerves in particular.

In spite of a narrow operating field, this technique also allows easy access to hidden areas as well as extensive exploration of the neck without full-scale surgical dissection: the total length of the wounds is even smaller than those caused by minimal open surgical approaches. As with other minimally invasive techniques, less pain and better cosmetic results may be expected from this procedure since muscle tissue is left intact and skin incisions are smaller. The latter may also decrease the likelihood of postoperative wound complications. Transection of the neck muscles, and the subsequent functional loss that may result, can also be avoided. The small size of incisions is appropriate for the extraction of small specimens such as parathyroids.

In some endoscopic procedures such as thoracoscopy, the fact that palpation is not possible can be a disadvantage. However, as there is no need for palpation in parathyroid surgery, the use of endoscopic techniques is of no inconvenience.

As mentioned by Gagner, placing the patient in the supine position with his neck slightly extended prevents the cervical muscles along the trachea from being stretched. This facilitates pneumodissection and creates the widest space possible.

No hypercarbic episode was recorded, contrary to what was previously reported by Gagner, possibly because our insufflation pressure was much lower (12 mm Hg initially, decreased to 6-8 mm Hg after the working space had been created). As was experimentally demonstrated in the retroperitoneum, pneumodissection in the neck would not appear to induce increased $p\text{CO}_2$ at low pressure and using modulation of insufflation. Nevertheless, we believe that continuous end-tidal $P_{\text{ET}}\text{CO}_2$ monitoring is mandatory for such a procedure.

Capillary bleeding is avoided with pneumodissection. Vascular control was efficiently achieved by bipolar coagulation. If clips should be required, 3 mm appliers would need to be developed.

The 2 mm instruments which are generally used for endoscopic procedures in babies and infants were not used, as they are not rigid enough to lift up the thyroid. Two mm bipolar coagulation and scissors are too sharp to be used as dissectors; for this reason we used a 3 mm bipolar forceps (Micro-France) which has smooth spatulated ends and can either be used to coagulate or to dissect.

As the procedure was bloodless, no suction probe or gauze pads were used. Thus, we do not know if the usual laparoscopic technique of suction and irrigation would be appropriate as suction would collapse the small space.

Our operating times were 207 and 130 min, which included the forearm implantation of one of the parathyroid glands in the first case. It was much longer than by the open procedure. Gagner took 5 hours, while the operations performed by Yeung lasted between 120 and 150 minutes. However, it must be remembered that the operations we performed were a first attempt of such a procedure and, with experience, future endoscopic interventions of this type should see a significant decrease in duration.

This initial experience shows that endoscopic parathyroidectomy can be performed in children as safely and reliably as previously reported in adults. It provides

the surgeon a minimally invasive procedure and as good or even better view of the parathyroids than with open approach. However, these benefits must be measured against the relative drawbacks: the duration of the operation, the use of expensive specialized instruments, the need for expertise in endoscopic operations. Careful evaluation on a case by case basis is therefore mandatory.

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Laparoscopy in Trauma

Brian F. Gilchrist, Evans Valerie and Julie Sanchez

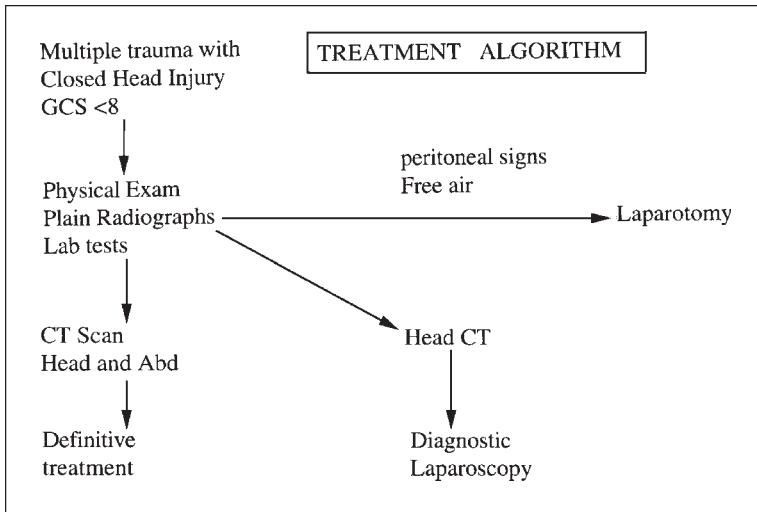
Keith Georgeson wrote that laparoscopic cholecystectomy was the revolution, and that the rest is evolution. Well, as any trauma surgeon will tell you, trauma surgeons are the Neanderthals of surgery; thus it is no surprise that the use of minimally invasive techniques has lagged in the trauma setting, especially in pediatric trauma. However, as technology has advanced with more miniature equipment, some dauntless pediatric surgeons have pushed forward on the frontiers of trauma.

The trauma war has always been waged by warriors. The warriors were always men in the midst of battle, both civilian and military. Frequently, they were big men, and men of intrepid character or enormous bravery. These men were incisive, decisive and not given to foolishness, gadgetry, neurosis or uncertainty. They approached the trauma patient with a clear plan, scalpel in hand and a willingness to wrestle the devil of uncertainties. Trunkey would bark "neck to toes, table-top to table-top," and one knew that the cutting might go from xyphoid to pubis. No uncertainty was sustained.

Theirs was a tried and proven way from Baron Larrey to Don Trunkey. They made big incisions, clamped vessels with large hemostats and sewed with monstrous needles. They saved thousands from death, disability and the devil, too. Blaisdell imprinted in his men's minds that incisions "heal from side to side, not from end to end." This was a philosophy, but a philosophy that had its under-pinnings jolted by the introduction of laparoscopic cholecystectomy in the 1980s.

Trauma surgeons recognize that acute injury necessitates quick thinking, even quicker answers and rapid diagnostics. Trauma surgeons have been trained to move patients expeditiously from receiving areas to either a radiology suite or to an operating room. The approach in the operating room was to open the affected cavity with a large incision. However, with the trinity of Advanced Trauma Life Support training, rapid scanners and truly trained traumatologists, this *modus operandi* changed. A dramatic shift in the paradigm has also occurred because of the development and use of the laparoscope. Certainly, laparoscopy has replaced the use of diagnostic peritoneal lavage for evaluation of the abdomen, as our abilities have gone from the rather primitive to the sublime; note that we once stuck a rubber hose in the abdomen and filled it with saline. Now, we take a well made, technologically superior laparoscope and view the entire abdominal contents without difficulty.

In fact, the laparoscopist can discern a great deal of specific information within minutes. However, to do so, one must be facile, well-trained and circumspect. Remember that not all patients are candidates for laparoscopic evaluation in a receiving area or in an operating room.



What we have done at Brooklyn's King's County Medical Center Hospital, the busiest receiving area for childhood trauma in the United States, is to laparoscopically evaluate patients in the emergency room. We do so only in those children who have been already intubated and have a Glasgow Coma Scale of 8 or less. This allows us to make a small incision in the skin and to place a 2 mm camera directly into the abdomen after insufflation via a Veress needle. Since the patients are relatively small, an assistant manually rotates and moves the patient around for the laparoscopic surgeon. This allows easy access and visualization of all parts and organs within the abdominal cavity.

Certainly, the technical aspects of emergency room trauma laparoscopy are the same as described elsewhere in this book. However, there are few caveats that must be stressed in the trauma setting:

1. The laparoscopist must be well-trained and quick. Although, the patients who are selected are hemodynamically stable, speed is essential, as other organ systems may need evaluation and repair.
2. A tower with all of the necessary equipment must be readily available to the team. This is especially true when a trauma patient unexpectedly arrives in your receiving area without prior warning. The equipment must be "loaded and locked."
3. The last point is that it is paramount that an entire team be a part of the process. You must have people that you can rely on and everybody must be assigned their particular roles. If you are going to be facile and safe, everybody must know their role and place as the procedure is being done.

It is also essential that all of the children who are evaluated in the receiving area of your hospital be monitored. This includes blood pressure monitoring, EKG, heart rate and pulse oximetry during the laparoscopic procedure. One can either use an

open "Hassan" technique or a Veress needle technique. We have utilized both techniques and we have gone from a 3 mm introducing port to simply a 2 mm camera placed directly through the fascia without the use of a port. We place the camera in the umbilicus and produce a pneumoperitoneum of 14 mm of mercury with CO₂. We use other ports as dictated by need.

The use of laparoscopy in the emergency room allows us to evaluate the peritoneal cavity for the presence of blood, bile or particulate matter. The hemidiaphragms, liver, duodenum, spleen and pelvis are then examined. Visibility is optimized by the manual rotation of the patient, which your assistant can do for you.

The liver, spleen, diaphragm, bladder, small and large bowel are all very well seen by laparoscopy in these patients. The retroperitoneum is also evaluated for the presence of hematoma. All of the findings that we had were initially corroborated by CT scan. This allowed us to evaluate our ability to discover injuries. In fact, one child in whom diaphragmatic rupture was suspected by CT scan, was shown by laparoscopy to have an intact diaphragm. Had there been such an injury, then repair could have been done by techniques described elsewhere in this volume. The important point, however, is that the patient was saved a needless exploration.

The time needed to perform laparoscopy in the emergency room decreases with experience. This is directly related to the learning curve. You can expect that your team will be able to do this procedure in under 15 minutes after five or six cases. It should be stressed that your hospital needs to initially blind your laparoscopic surgeon from the CT scans, which should be done before the laparoscopic evaluation. This will allow you some way of quality assurance and standardization. Once you are confident in your abilities, as checked against the CT scans, you can then do all of your evaluations within the confines of the emergency room.

Certainly, more complex intraabdominal surgery can be done utilizing laparoscopic techniques. This is well covered in other parts of this book. However, we emphase in this chapter the need for preparation for trauma patients. One must be ready to use the laparoscope in the trauma setting either in the emergency room or the operating room. In most institutions, children with blunt abdominal trauma are evaluated with hematologic and biochemical studies, radiography, CT and DPL. We would argue that DPL should be of historical note only. We feel that this procedure is hazardous in a small child because of the proximity of major vascular structures to the abdominal wall. It should be avoided. Also, the radiology suite is frequently remote from the emergency room and is not staffed with personnel trained to manage dramatic changes in the condition of a critically injured child. Moreover, a CT scan is not almost immediately available, especially in some small community hospitals. Diagnostic laparoscopy performed in a receiving area offers the advantage of swift and specific assessment of an injured abdomen. The procedure reduces the time spent in the radiology suite, offers a specific diagnosis and reduces the delay in obtaining neurologic or orthopedic intervention. We would argue strongly that as abilities increase and equipment become better, many of the injuries that one might encounter in the traumatized child can be handled with laparoscopic techniques as described elsewhere in this book.

Other than the acute trauma setting as described, one can use laparoscopy to evaluate trauma patients in the Intensive Care Unit. Intensive Care Unit patients who may have occult injury and may not be easily or safely transferred to an operat-

ing room can be evaluated with the use of laparoscopic techniques as described above. We have utilized the laparoscope in the pediatric ICU setting to evaluate abscess formation, ischemic bowel and extrahepatic duct injury. It has proven to be very sensitive and specific. When injuries are discerned utilizing these techniques, one then has to decide if one is going to approach the problem either conventionally or laparoscopically. Certainly, the editor and many of the authors of this book will argue strongly that if the patient is stable, laparoscopic techniques and minimal invasive surgery should be undertaken.

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Operative Fetoscopy

Craig T. Albanese

Introduction

Open fetal surgery has been successfully performed to treat a variety of life threatening congenital anomalies. However, preterm labor resulting from the hysterotomy is the predominant limiting factor preventing the broad application of open fetal surgery. Furthermore, open fetal surgery requires partial exteriorization of the fetus resulting in fetal hypothermia and related secondary physiologic perturbations which may cause increased fetal morbidity.

To circumvent many of the problems associated with open fetal surgery, techniques and instrumentation for operative fetoscopy were developed over a ten year period. It was hypothesized that minimally invasive fetal surgery, by inducing less uterine trauma, would ameliorate preterm labor and maintain fetal homeostasis by protecting the intrinsic physiologic fetal milieu. The techniques for postnatal endoscopic surgery required significant modifications to meet the unique requirements of fetoscopic surgery. Among the novel challenges of fetoscopic surgery were: variable placental location, a vascular uterine wall with layers of membranes tenuously attached to the anterior surface, a variable uterine wall compliance, a somewhat mobile fetus, the necessity of operating within a fluid medium, a cramped operative field, and suboptimal monitoring of the fetus with no intravenous access.

This chapter chronicles the evolution of minimally invasive fetal surgery. The technical details of fetoscopic surgery and maternofetal monitoring techniques are presented. Lastly, specific disorders potentially amenable to fetoscopic intervention are discussed.

General Fetoscopic Techniques

Anesthetic Considerations

There are six basic objectives of maternofetal anesthetic management: 1) maternal safety; 2) avoidance of teratogenic agents; 3) avoidance of fetal asphyxia; 4) fetal anesthesia and monitoring; 5) uterine relaxation; and 6) prevention of preterm labor. The mother and fetus are anesthetized with an inhaled halogenated agent which also provide profound uterine relaxation. At the beginning of the clinical experience with fetal surgery halothane was the preferred agent, but for the last several years isoflurane has become the standard anesthetic. It is delivered in 100% oxygen with muscle relaxants to provide unconsciousness, amnesia, and analgesia for the mother, as well as fetal and maternal immobility and uterine relaxation that aids the surgeon. Intraoperatively, terbutaline and nitroglycerin are administered as needed to achieve further uterine relaxation not achieved primarily by the inhaled halogenated volatile

anesthetic. To prevent preload reduction and decreased uterine blood flow, the mother is never positioned supine, which would allow the gravid uterus to produce aortocaval compression. Instead, a roll is always placed under the right hip, displacing the uterus to the left. For many procedures, instrument manipulation is facilitated by placing the mother in lithotomy position with the knees low. The surgeon and assistants are positioned on either side of the patient and between the abducted lower extremities. A lower extremity sequential compression device is used throughout the procedure. The intraoperative set-up is pictured in Figure 28.1.

Uterine Access

The uterus can be accessed percutaneously, via a mini-laparotomy, or through a full low transverse abdominal incision. Intraoperative ultrasonography is used to map the placental edge and to safely guide the introduction of the trocar(s). In the case of an anterior placenta, either a laparotomy is performed and the uterus is manipulated forward for posterior/superior insertion of trocars, or the trocar(s) may be inserted through a lateral “window”, taking care to avoid the lateral-coursing uterine vessels and round ligament. Delicate handling of the uterus, hemostasis and prevention of membrane separation is essential. There are a variety of types and sizes of trocars for fetoscopy. Small (1.6 to 5 mm) non-radially expanding ones can be placed percutaneously (usually with Seldinger technique) without amniotic fluid leak although bleeding can occur from the entry site, adding to the already cloudy amniotic fluid. Trocars with balloons can control bleeding from the myometrium and prevent membrane separation at the insertion sites although they are relatively large (5 and 10 mm), are not amenable to percutaneous insertion, and lack a sharp insertion system. Radially expanding trocars, when inserted with a sharp diamond-shaped needle, control bleeding, make only an initial 1.9 mm opening in the membranes, and can be dilated from 2 mm to 10 mm, if necessary. These trocars are not inserted percutaneously and are placed with ultrasound guidance after placing a partial-thickness “U”-stitch that allows one to pull up on the uterus as the trocar sheath is advanced. All non-percutaneously placed trocar sites are closed with a partial thickness (myometrium only) figure-of-eight absorbable suture and fibrin glue.

Working Medium/Irrigation System

For complex procedures, a specially designed fetoscopic irrigation system is used to deliver high flows at constant physiologic temperatures (37° C) (Fig. 28.2). In contrast, the temperature of the fetus in open fetal surgery has been documented to drop to 32° C within 10 minutes. High flow is often necessary for effective visualization when working in a fluid medium obscured by cloudy amniotic fluid and blood. A heat exchanger keeps the fluid at 37° C. By bathing the fetus in warm lactated Ringer's throughout the case, the physiologic milieu of the fetus is maintained. Despite high volumes of fluid perfused into the uterus (up to 40 L/per operation) less than 3% was systematically absorbed and maternal hypervolemia or altered maternal electrolytes was not noted. Working in a fluid medium avoids the potential complications of CO₂ insufflation (air embolism or fetal acidosis) and allows intraoperative sonography, a crucial component of the procedure that would be impossible if one was working in a gas medium.

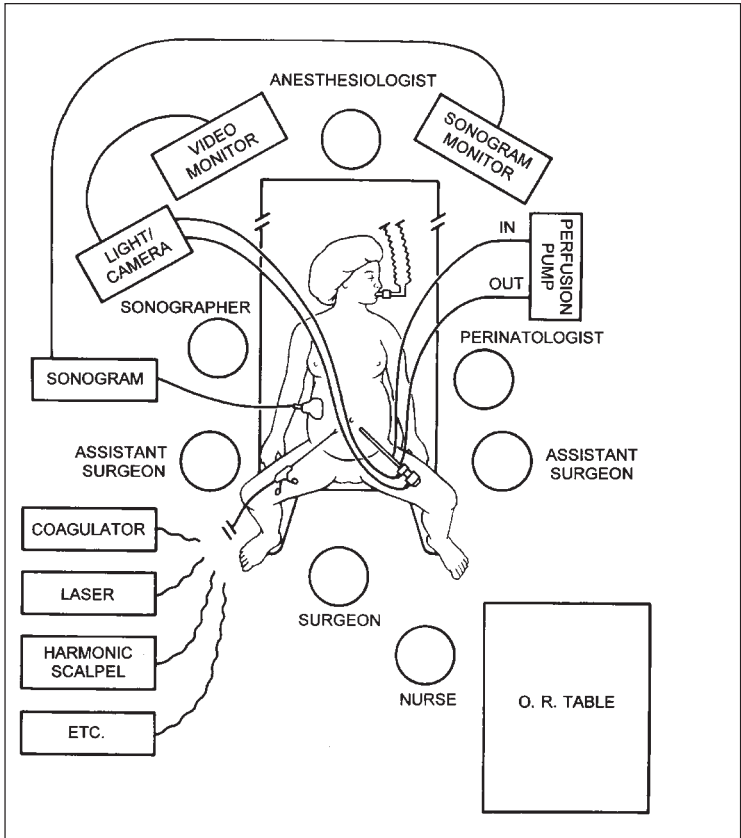


Figure 28.1. Maternal positioning and intraoperative set-up for fetoscopic surgery.

The safest medium for endoscopic work in the uterus is an isotonic solution. A problem with saline amnioinfusion is the difficulty of coagulating blood vessels because the current between the bipolar tips disseminates into the electrolyte rich solution.

Once the uterus is distended with an adequate amount of fluid as judged by manual palpation, the fetoscopic irrigation system maintains this balance. However, given the changing uterine compliance during the procedure, volume controls are used to infuse or suction fluid as needed. The irrigating pump is connected to a hysteroscope which is ideally suited to fetoscopic surgery. The telescope is inserted into two concentric sheaths. Fluid is pumped through the inner sheath which exits at the tip of the telescope providing excellent visualization. If the operative field is obscured by bleeding, increasing the flow effectively clears the field. Multiple perforations at the tip of the external sheath allows for effective fluid suctioning. Telescopes and their sheaths range from 1.0 to 2.7 mm with varying lengths and flexibility.

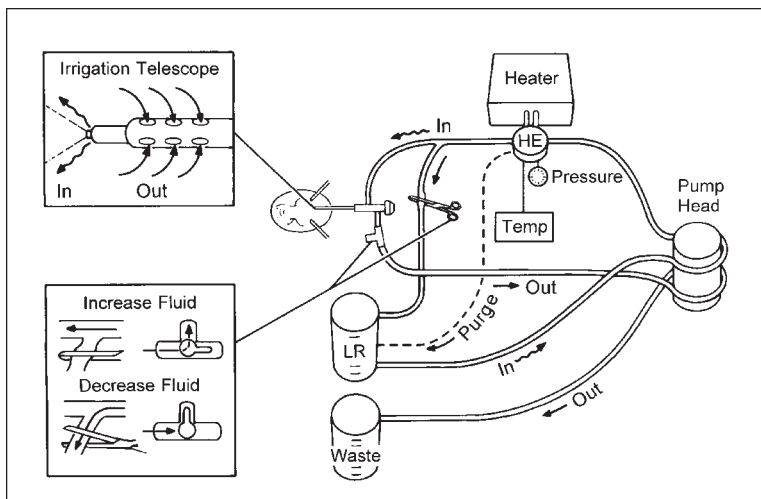


Figure 28.2. Schematic diagram of fetoscopic perfusion pump. Upper inset demonstrates fluid flow into and out of the hysteroscope. Lower inset demonstrates the ease of adjusting flow with appropriately placed stopcocks and clamps.

Those larger than 2.0 mm can be angled and are of the rod lens configuration; less than 2.0 mm are 0° and fiberoptic.

Monitoring the Fetus During Fetoscopic Surgery

Fetoscopic Placental Vessel Catheterization

One general limiting problem for fetal surgery is the lack of intravenous access to the fetus in the perioperative and postoperative period. A “fetal IV” and/or arterial line would allow fetal blood sampling, pressure monitoring, administration of blood products, intravenous fluids and pharmacologic agents. An ideal technique for fetal vascular access should be safe for the mother, minimize the risk of infection, provide no intraamniotic lines to entangle the fetus or umbilical cord, remain patent throughout gestation, and have minimal risk of vasospasm to the umbilical cord. This has been successfully accomplished experimentally but not yet clinically. This technique shows that chronic access to the fetal circulation is safe for the fetus and mother in a primate model.

Fetoscopic Surgery Monitoring

A variety of monitoring parameters during human fetoscopic surgery have been used. Periodic sonography monitors heart rate and contractility. Direct uterine palpation is required to assess the degree of uterine distention and intrauterine fluid balance is adjusted accordingly. The irrigating solution is warmed and maintained at 37°C -38°C. During open fetal surgery, a radiotelemeter is implanted under the fetal chest wall which transmits continuous fetal electrocardiogram, temperature, and intrauterine pressure. Currently, NASA is conducting large animal experiments

using a miniaturized radiotelemeter that can be inserted through a 3 mm trocar and safely float in the amniotic space during and after a fetoscopic procedure.

Postoperative Care

Preterm labor occurs 100% of the time after fetal intervention, although less vigorously after fetoscopy versus open fetal surgery. The typical postoperative regimen used for spontaneous preterm labor includes external monitoring with a tocodynamometer, bedrest, intravenous magnesium sulfate, intravenous or subcutaneous betamimetics, and oral prostaglandin synthetase inhibitors. The overall clinical experience suggests that this regimen is inadequate for fetal surgery. Future work in this area will need to address the unique contribution of uterine injury and manipulation during fetoscopic surgery in causing the cascade of events leading to preterm labor.

Indications for Fetoscopy/Fetoscopic Surgery

First Trimester Embryoscopy/Fetoscopy

Embryoscopy is indicated for the early investigation of a pregnancy in a few families at high risk of recurrence of genetic conditions showing external fetal abnormalities. Early, karyotypically normal fetuses may have only subtle, non-specific ultrasound findings that may be part of a lethal syndrome. This may be amenable to documentation by the presence of abnormal external morphology as seen by embryoscopy. This is performed in an extracoelomic fashion between 9 and 12 weeks' gestation, before the amnion and chorion fuse. It can be performed by either the transcervical or transabdominal routes using a fetoscope that ranges from 0.5 mm to 1.7 mm, passed through a 18 to 21 gauge needle.

Congenital Diaphragmatic Hernia

Most fetuses diagnosed with congenital diaphragmatic hernia (CDH) prior to 24 weeks' gestation die despite optimal postnatal management including extracorporeal membrane oxygenation. Two decades of experimental work and clinical observation has now resolved much of the uncertainty about the natural history of fetal CDH. Fetuses with a good prognosis can be identified by the absence of liver herniation, high lung-to-head ratio (LHR), and late herniation of viscera. Although complete repair of the defect in utero works for fetuses without liver herniation, it does not improve survival over standard postnatal care. Therefore, fetuses in this group can be treated postnatally with good outcomes. Fetuses with CDH who have a poor prognosis with postnatal treatment can now be selected on the basis of liver herniation and a low LHR. Unfortunately, in this subset of fetuses with liver herniation, open in utero diaphragmatic hernia reduction and complete repair proved unsuccessful because of umbilical vein occlusion while reducing the liver into the abdomen. Fortunately, a serendipitous observation led to the idea that temporary tracheal occlusion might successfully be used to gradually enlarge the hypoplastic fetal lung. Temporary tracheal occlusion or the PLUG (Plug the Lung Until it Grows) technique has worked experimentally and clinically to reverse the pulmonary hypoplasia associated with CDH. It increases lung mass, improves gas exchange, and reduces the viscera. Initial clinical experience showed that the PLUG strategy works in human fetuses, but complications from open fetal surgery limited survival. After

a decade of experimental work, techniques for fetoscopic tracheal occlusion have been developed.

Fetal Obstructive Uropathy

Prenatal intervention is possible for select fetuses with urinary tract obstruction whose renal and pulmonary development is threatened but potentially salvageable. Methods of fetal urinary tract decompression continue to be refined and now include open fetal surgery, endoscopic fetal intervention and the placement of percutaneous fetal shunts under sonographic guidance. Catheter shunts are not always successful in decompressing the obstructed bladder and carry a complication rate of approximately 25% due largely to displacement and obstruction.

Open fetal surgery can relieve bladder outlet obstruction, but it carries the attendant risks of open surgery for the mother and fetus. Percutaneous methods carry less risk but are unreliable for long-term bladder decompression. However, a minimally invasive technique using fetoscopic surgery holds a great deal of promise for treating congenital urinary tract obstruction in utero. Shunts can be placed under direct vision thereby ensuring proper positioning and minimizing the risks to the fetus. A shunt that does not migrate and occlude due to tissue ingrowth has yet to be constructed.

Percutaneous cystoscopy has recently been performed to treat lower obstructive uropathy (posterior urethral valves). A trocar is placed through the maternal abdomen and uterus into the fetal bladder. Fetal cystoscopy is performed with a fiberoptic endoscope to allow visualization of the bladder, urethra, and ureteral orifices. Urethral vesicoamniotic shunts have been placed as well as endoscopic fulguration of the valves performed. Although experience is limited, in utero cystoscopy may aid in confirming ultrasound diagnosis, enhance our prognostic abilities, and facilitate the introduction of novel techniques such as urethral vesicoamniotic stents which may have a lower incidence of dislodgment. Fetoscopic techniques may also allow the creation of a fetal vesicostomy without the need for a shunt.

Fetoscopic Umbilical Cord Ligation

In some twin pregnancies abnormal chorionic blood vessels in the placenta connect the circulation of the two fetuses and perinatal mortality is high for twin-twin transfusion syndrome and for acardiac-acephalic twin syndrome. Although, serial amniocenteses have worked in many instances of twin-to-twin transfusion syndrome, photocoagulation of the abnormal placental vessels using a neodymium:yttrium-aluminum-garnet (Nd:YAG) laser light using a 400-600 μm fiber through the hysteroscope improves outcome in select, severe cases. Fetoscopic umbilical cord ligation, using a variety of methods, has been performed in human fetuses for a variety of other complications of twinning.

Amniotic Band Syndrome

Amniotic band syndrome is a frequent cause of fetal deformations involving the limbs, craniofacial region, and trunk. The spectrum of morbidity ranges from the formation of syndactyly to limb amputation. This syndrome may be fatal if umbilical cord constriction is present. If amniotic band syndrome causes umbilical cord constriction, fetoscopic release is warranted. Less severe forms of this syndrome do

not warrant fetoscopic intervention at this time given the potential fetal and maternal morbidity.

Sacrococcygeal Teratoma

Although most fetuses diagnosed with sacrococcygeal teratoma have an uneventful intrauterine course, a small subset (<20%) with large tumors develop hydrops from high-output failure which leads rapidly to fetal demise. Excision of the tumor with open fetal surgery reverses the pathophysiologic process but is fraught with the usual limitations of open fetal surgery. Fetoscopic techniques are being developed that can occlude the feeding vessels using laser technology.

Cleft Lip Repair

The theoretical basis upon one would repair an isolated fetal cleft lip/palate is based on the unique, relatively scarless wound healing of the early gestation fetus. Prior to clinical application, several technical hurdles regarding fetal cleft lip repair must be overcome. Specifically, the current Millard rotation-advancement repair commonly performed in many institutions will be very difficult to perform fetoscopically. It is likely that a new operation which is an amalgam of Millard's repair but simplified for the particular requirements of fetoscopic surgery will be required. Smaller specialized instruments will be required for precise handling of the tissues.

Congenital High Airway Obstruction Syndrome

Congenital high airway obstruction syndrome (CHAOS) is usually caused by laryngeal atresia and rarely by isolated tracheal stenosis. The constellation of findings include large echogenic lungs, flattened or inverted diaphragms, dilated airways distal to the obstruction, and fetal ascites and/or hydrops. For select fetuses who develop hydrops from lung overdistension caused by increased fluid accumulation, in utero fetoscopic tracheostomy could potentially relieve the obstruction and cause resolution of the hydrops. This has not yet been performed clinically.

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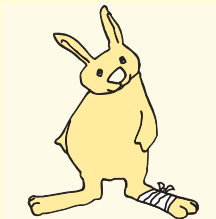
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