29 Principles of Minimally Invasive Surgery in Children

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Abstract

The development of MIS has revolutionized surgery over the last 30 years. MIS in pediatric surgery was slow to advance but over the last 20 years has rapidly expanded to include all major pediatric surgical procedures in infants and children. The benefits to the patient are great but the technical hurdles are many because of the varied size and physiology of this patient population. This chapter gives an overview of the basics of MIS in infants and children

Keywords

Minimal invasive surgery · Laparoscopy · Thoracoscopy · Robotic surgery

Introduction

The advent of minimally invasive surgery (MIS) has been one of the greatest surgical developments of the twentieth century. The first experimental laparoscopy was performed in an animal model by George Kelling, a German surgeon, in 1901 by the introduction of a visualizing scope in

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the peritoneum of a dog. It was followed by first clinical description of laparoscopy and thoracoscopy in humans by Jacobsen in 1911. These initial attempts were greatly assisted by development of fiber optics, electronic CO_2 insufflators, and electronic miniature cameras, among others, which gradually led to the modern laparoscopic era. Today, the benefits of MIS are well recognized including, but not limited to, the surgeon's ability to perform major intracavitary procedures with significantly less pain and morbidity than associated with traditional open surgery. While MIS techniques were embraced by adult general surgeons soon after the first laparoscopic cholecystectomy was performed in 1987 by Philippe Mouret, its utilization in pediatric community has progressed much more slowly. This was due to poorly adaptable equipment for use in children in earlier years, combined with the technical complexity of operating in small spaces in most pediatric surgical patients. Additionally, it was initially difficult to prove whether infants undergoing laparoscopy, who are unable to articulate their distress, have less postoperative discomfort and stress than those undergoing conventional surgical procedures. However, over the last decade, many of these initial obstacles have been overcome with increasing surgeon's expertise, marked improvements in video equipment, and instrumentation. Laparoscopic procedures that can now be performed safely include, but are not limited to, pyloromyotomy, appendectomy, fundoplication with or without gastrostomy for gastroesophageal reflux disease, duodenal atresia repair, Ladd's procedure for malrotation, colonic pull-through for Hirschsprung's disease or anorectal malformation, cholecystectomy, Kasai procedure for biliary atresia, and choledochal cyst excision. The scope of thoracoscopy in the pediatric population is also expanding with refinements in technology and technique. Initially used primarily for decortications in tuberculosis, empyema, and diagnostic intrathoracic lesions, thoracoscopy is now used extensively for lung biopsy and wedge resection in patients with 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 neoplasms. It also allows excellent excess and visualization for biopsy and resection of various mediastinal masses such as lymph nodes, thymic lesions, cystic hygromas, foregut duplications, ganglioneuromas, and neuroblastomas. In recent years, its use has been extended to more advanced thoracoscopic procedures like repair of diaphragmatic hernia, repair of tracheoesophageal fistula, ligation of patent ductus arteriosus, and division of vascular rings. Furthermore, advanced laparoscopic and thoracoscopic skills combined with the availability of appropriately sized instruments have made these minimally invasive procedures feasible for neonates and infants, even those weighing less than 5 kg.

Basic Principles

The general principles for MIS include the appropriate patient selection, operating surgeon's comfort with the procedure involved, knowledge of available technology, and the appropriate intraoperative management. Indication and nature of the procedure, port sites, and alternate approaches along with the risks and benefits for the surgery should be discussed with the parents and patients, if old enough.

Patient Selection and Preoperative Workup

Prior to any laparoscopic or thoracoscopic procedure, all children should undergo preoperative evaluation, same as those required prior to any open surgical procedure with special attention to their cardiorespiratory status. There are no absolute contraindications for performing laparoscopic or thoracoscopic procedures in children. However, when the patient is hemodynamically unstable, is not on conventional ventilation, cannot be safely transported to the operating suite, or is of extremely low birth weight, the pros and cons of an MIS approach must be considered. Relative contraindications for MIS approaches include difficulty to achieve pneumoperitoneum or pneumothorax and adhesions from previous surgery precluding optimum visualization. With increasing surgical expertise with MIS, procedures which were considered impossible in these difficult situations and in small neonates only a few years ago are now routinely performed at many centers.

For most thoracoscopic procedures, similar principles apply for the preoperative work-up. Most intrathoracic lesions require routine radiographs as well as computed tomographic scan or magnetic resonance imaging. A thin-cut, high-resolution CT scan is especially helpful in evaluating patients with ILD or infectious conditions to identify the optimal site for biopsy. Intraoperative endoscopic ultrasound is an emerging technology which can prove to be extremely helpful in cases with deeper small lesions and can potentially compensate for the lack of tactile sensation. Preoperative imaging should also be used to determine patient position and optimal port placement for both laparoscopy and thoracoscopy.

Ergonomics

The importance of ergonomics in the setting of MIS cannot be overemphasized. Ergonomic integration and suitable laparoscopic operating room environment are essential to improve efficiency, safety, and comfort for the operating team. Few of the challenges faced by the training surgeons in MIS are absence of direct three-dimensional vision, loss of depth perception, loss of peripheral vision, loss of tactile feedback, fulcrum effect with tremor enhancement, and decoupling of the visual and motor axes. Furthermore, it has been observed that the operating room surgeon assumes a more static posture during MIS compared to traditional open approach, potentially causing disabling and harmful effects. To overcome these factors, it is advisable to follow few basic rules of laparoscopy:

- Choose an ergonomically convenient operating position for yourself.
- Adjust the operating table height to keep instruments at your elbow level.
- Adjust the monitor image at or within 25 optimal degrees below the horizontal plane of the eye to avoid neck strain.
- Second monitors should be used as necessary for assistants.
- Port positioning is dictated by the individual surgeon but should follow the rule of triangulation (Fig. 1) to allow the instruments to work at 60–90° angle with the target tissue without interference with each other and the abdominal wall.
- Adjust manipulation angle ranging from 45 to 75° with equal azimuth angles when possible.
- Arm should be slightly abducted, retroverted, and with inward rotation at shoulder level. The elbow should be bent at about 90–120°.
- Last but not the least, do not hesitate to convert to open procedure when needed.

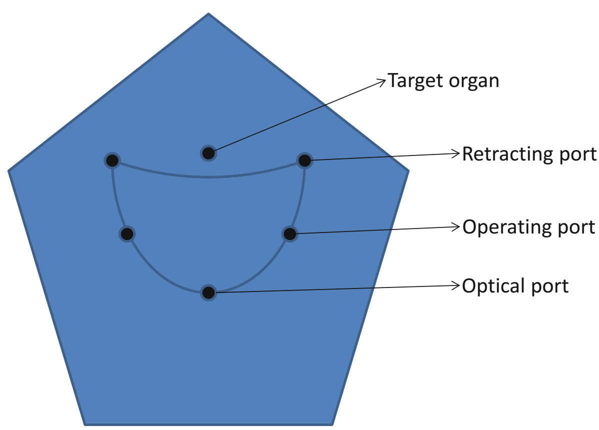

Fig. 1 Ergonomics, principle of triangulation in laparoscopy

Advances in Technology and Intraoperative Considerations

Besides the surgical skills of the operating surgeon, choosing correct instruments and settings plays a crucial role in successfully performing any MIS procedure. In earlier years, most of the centers were using the equipment and instrumentation designed for adults and large children. Instruments were either available in 5 or 10 mm diameter or were too long (30–35 cm), making it difficult to manipulate safely in smaller spaces in young children and neonates. As more pediatric surgeons began performing minimally invasive surgery in infants, manufacturers developed an interest in development of minilaparoscopy (3 mm and 5 mm) instruments. Additionally, telescopes have also evolved in quality, length, diameter, and angulation. Originally, only a long (35 cm) 10 mm scope with 0° angulation was available, which now is available in much smaller diameters and length. The advent of greater scope angulation up to 70° can be of great asset in the performance of more advanced procedures. Most of the procedures in children can be performed using short 20 cm, 4–5 mm, 30°, and 45° telescopes. Some like using a 70° angulation scope to evaluate the presence of contralateral inguinal hernia in a child while performing an open repair for the known unilateral defect. Other major advancements in the field include availability of improved energy sources for vessel and tissue sealing. These devices use radio-frequency (RF), bipolar, or ultrasonic technology and can safely seal and divide vessels up to 5 mm or cut across lung or liver with relatively hemostatic and air-tight seals. These devices have played an especially important role in the advancements of MIS procedures in children eliminating the need for suture ligation and division, a technically demanding task especially in these smaller patients. However, these devices are still not made in smaller sizes for neonatal MIS, and so their use in this patient population can be difficult.

Probably of greatest import was the evolution of the CO_2 insufflator. Use of less sensitive adult insufflators to perform MIS procedures in young children in the 1990s was difficult and potentially life threatening due to high insufflation pressures and problems with overdistension. With the advent of highly sensitive neonatal insufflators releasing small puffs of air over shorter period of time, the issue of overinsufflation is resolved. These units can flow at levels of 1/l/min or less and can also heat the CO_2 helping prevent unwanted cooling of smaller patients. The process of creating the ideal instrument for children less than 5 kg took many years to refine and is still in evolution.

One should try to use the best technology available if feasible, especially while performing MIS in neonates in confined spaces, including high-resolution cameras, 10–15× magnification on the optical system to reduce the visual challenge, and use of modern CO_2 insufflators. Operations should be performed using specially designed 3 mm wide, 18–20 cm long instrumentation for children and smaller-diameter (4.0 mm, 2.7 mm) telescopes. Insufflation pressures ranging between 8 and 15 mmHg and flow rates of 1–3 l/min are recommended for laparoscopy and should be adjusted based on patient's age, size, and comorbidities. Valved cannulas of the appropriate size (3 mm, 4 mm, 5 mm) should be used to prevent CO_2 escape. It is often difficult to keep these trocars, especially the reusable ones without screws or ridges, from sliding in and out because of the thin abdominal wall of most infants and small children. The trocar can be stabilized by placing a small section of rubber or silastic catheter on the shaft of the trocar at the desired height. This rubber "stop" can then be sutured to the skin to prevent slippage (Fig. 2). Again, pediatric insufflators should be used, if available, to avoid problems with accidental overinsufflation and distension and related complications. All patients should be carefully monitored intraoperatively by electrocardiogram, pulse oximeter, and end tidal CO_2 monitor.

For patients undergoing thoracoscopic procedures, single lung ventilation may be desired in some cases. This can be achieved in most instances by selective intubation on the opposite side. Occasionally a bronchial blocker or a double endoluminal endotracheal tube can be used to achieve collapse of the lung. However, these

Fig. 2 Stabilizing 3 mm trocar with stitch in a small child

procedures require more technical expertise by the anesthesiologist to place fast and effectively, and the smallest double lumen is a 24 Fr and cannot be used in smaller patients. We have found the main stem intubation to be the most reproducible and efficient technique.

In many patients CO_2 insufflation alone is enough to give adequate access. The patients can have a standard tracheal intubation, and a low-flow (1 L/min), low-pressure (4–6 mmHg) CO_2 insufflation can be used to assist with collapse of the involved lung. Pressures and flow can then gradually be adjusted to improve visualization depending on patient's physiologic status. This is the preferred technique for mediastinal masses, esophageal atresia repair, and other non-lung parenchymal procedures.

Operating room setup for thoracoscopy is shown in Fig. 3. Problems with overinflation and associated hemodynamic consequences have been minimized by optimal anesthetic management and availability of modern CO_2 insufflators.

Technical Considerations

General technical principles for any MIS procedure remain the same as open surgery. Communication, describing the procedure, should take

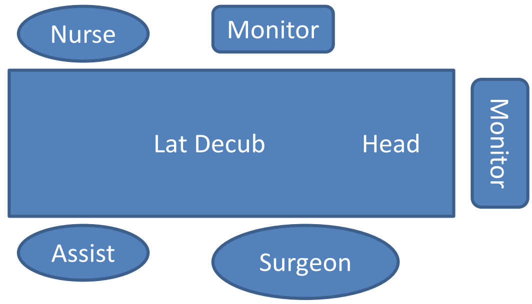

Fig. 3 Operating room setup for thoracoscopic lung resection

place between all the supporting teams prior to starting the surgery for optimal intraoperative environment and safe patient outcomes. Preoperative bladder decompression can frequently be obtained by manual pressure in children after they are anesthetized. Foley catheterization should be considered for procedures involving pelvic dissection including laparoscopic pull-through and imperforate anus in anticipation of a prolonged operation.

Patient positioning is of paramount importance and should be guided by the nature of the procedure. In general, gravity can be used to assist with the exposure of the desired area. For most upper gastrointestinal procedures, patient is positioned at the end of the table with surgeon standing between the patient legs with patient in reverse Trendelenburg position (Fig. 4). For lower abdominal surgeries, the monitors are placed at the bottom of the table with the surgeon standing at the right or left side of the table. For many procedures in small infants, such as pull-through, the infant can be placed crosswise on the table giving the surgeon the ability to stand at the child's head or feet depending on which part of the procedure is being performed.

For thoracoscopic procedures, positioning to allow gravity to act as a retractor is the key for obtaining good exposure for the procedure. For anterior mediastinal operations, the patient is placed supine with the operative side elevated 30–40° to allow access for trocar placement. A modified prone positioning provides a good exposure for posterior mediastinal masses, esophageal

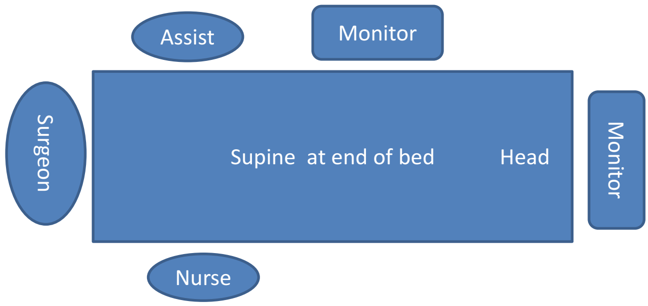

Fig. 4 Operating room setup for upper abdominal laparoscopic procedures

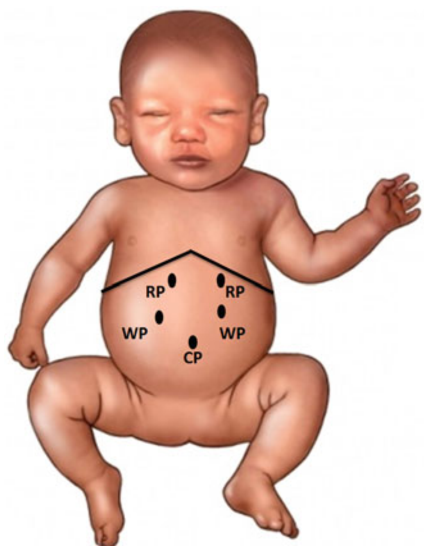

Fig. 5 Port placement for Nissen fundoplication

atresias, and other posterior structures. For decortications, lung biopsy, and lobectomy, a lateral decubitus position is optimal.

Ports should be widely placed to allow adequate working space and should especially be planned wisely in smaller neonates. Port placement for fundoplication and thoracoscopic procedures is shown in Figs. 5 and 6. In general, camera port should be in the middle and "above" with two working ports on either side, directed toward the area of interest. The optimal angle for the two working ports in relation to the point of greatest dissection is 90°, as this improves the ability to perform complex maneuvers such as suturing. Insufflation is obtained through insertion of the Veress needle in the umbilicus for laparoscopy which is followed by placement of the largest port. Alternatively, a cutdown or Hassan approach can be used depending on surgeon's comfort and familiarity with the technique. In younger children, often there is an umbilical hernia, and the initial trocar can safely be introduced through the hernia defect. Special care should be exercised when inserting ports in the pliable, thin abdominal wall of infants and young children to avoid inadvertent injury to underlying viscera. For complex procedures the anesthesiologist should ensure that the patient is adequately paralyzed or relaxed to help with intra-abdominal visualization. For 3 mm ports, stab incision technique can be used. A stab incision is made in the skin and peritoneum to create a tract using no. 11 Bard-Parker blade followed by insertion of 3 mm cannula in the same tract. Occasionally, instruments can be placed directly through the stab incision tracts, which is ideal for assisting or retracting instruments. This technique is also helpful during decortication where direct insertion of instrument is helpful in removing the inflammatory peel and for introduction of staplers and retrieval bags when the space is limited. At the conclusion of the procedure, it is advisable to close the fascia for all ports 5 mm and above. For 3 mm ports, usually only the skin needs to be closed but hernias have been reported at these smaller sites. One should be careful to ensure omentum is not pulled into the tract with removal of the ports.

To reiterate, basic operative principles, similar to open surgery, should be followed to perform any MIS procedure and knowledge of anatomical planes and ability to visualize the same structures in a different orientation is the key to success. Additionally, importance of familiarity with instruments and basic operative setup cannot be

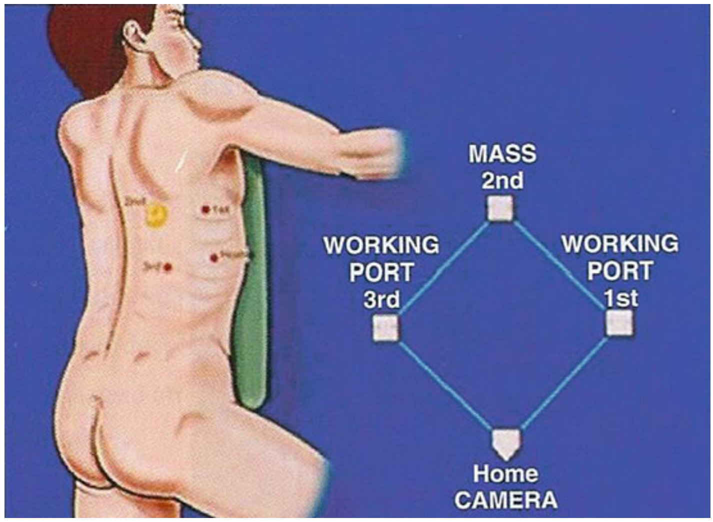

Fig. 6 Port placement for thoracoscopic lung resection: think of a baseball diamond: telescope should be at the home base with two working ports at first and third bases and target organ at the second base

overemphasized. In the incidences with instrument or equipment malfunction, surgeon should be able to troubleshoot or use an alternative plan.

Risks and Benefits

Laparoscopic procedures in neonates are not only safe and effective but result in significantly decreased morbidity with an earlier return of gastrointestinal function, quicker recovery, improved cosmesis, and reduced overall hospital cost. It causes reduced physiologic stress and postoperative pain leading to fewer pulmonary complications. This includes improved rates of extubation, shortened postoperative ICU stays, fewer days of supplemental oxygen, and decreased postoperative pneumonias. Pulmonary benefits afforded by minimally invasive approach play a significantly greater role in neonates with congenital cardiac disease where the ability to avoid respiratory complications has a dramatic benefit. For some procedures, like fundoplication, operative times are much shorter due to improved operative visibility. Multiple procedures can be performed simultaneously with minimal additional morbidity. The long-term benefit of decreased adhesion formation and scar tissue may be the strongest argument for pursuing this approach in neonates.

Average complication rate varies based on the experience of the operating surgeon and has been between 1% and 3% in our experience. Complications unique to a MIS approach include trocar related-injuries, trocar site bleeding or hernia, and wound infection but are extremely rare. Most of the intraoperative complications can be managed laparoscopically but depend on the technical expertise and comfort level of the operating surgeon. There is a steep learning curve for MIS in neonates, and surgeon should be prepared to convert to an open procedure when needed. Conversion rate to open in expert hands is less than 2% but conversion to open to complete a procedure safely should not be considered to be a complication.

Significant hemodynamic changes may occur following intraperitoneal or intrathoracic insufflation and change of patient position during laparoscopy or thoracoscopy, especially in children with congenital heart disorders. Use of MIS procedures in this population is controversial secondary to potentially deleterious effects of the pneumoperitoneum on cardiac index and pulmonary vascular resistance on an already compromised cardiopulmonary system, leading to cardiopulmonary instability. However, minimally invasive procedures can be safely performed in these high-risk patients with preoperative optimization of hemodynamic status and appropriate perioperative monitoring and care, with excellent outcomes. A multidisciplinary approach should be utilized which includes the availability of an experienced cardiac anesthesia team, skilled laparoscopic surgeon to avoid long operative times, keeping insufflation pressures to a minimum required, and effective communication between the team members. All of these components are critical to optimize surgical outcomes in these vulnerable children.

Evolution of Single Site Laparoscopic Surgery (SILS)

Constant strive for improvement led the surgeons to develop techniques like natural orifice transluminal endoscopic surgery (NOTES) in which the access to the peritoneum is achieved by passing an endoscope through a natural orifice (mouth or vagina), and the entire procedure is performed via multichannel endoscopes. However, considering this approach, one has to weigh the risk of visceral perforation needed for peritoneal cavity access vs. the cosmetic benefit offered by such technique. These concerns led to the evolution of single-site laparoscopic surgery, also known as LESS (laparoscopic single-site surgery), SAS (single-access site surgery), and SPA (single-port access surgery). This technique involves passage of multiple laparoscopic instruments through a single umbilical incision either through a single-port device with multiple conduits or through multiple closely spaced ports. Since its introduction, it has become the new paradigm in the field of MIS that promises virtually scarless procedures. SILS has been well described in adults for appendectomy, cholecystectomy, nephrectomy, splenectomy, and adrenalectomy and for appendectomy, cholecystectomy, and splenectomy in the pediatric literature.

Basic principles for the SILS remain the same as the MIS techniques. However, it frequently requires the use of flexible, high dexterity instruments with additional degrees of freedom and a multichannel single-port device. The instrument shafts are typically crossed to achieve the triangulation needed to perform these surgeries and to avoid the constant instrument collision with each other. Although most surgeons prefer to have these commercially available SILS-specific instrumentations, it can be performed by passage of multiple conventional laparoscopic instruments through a single umbilical skin incision or using the yin-yang incision described by Dutta in 2009. This is done by making a transverse or vertical incision through the umbilical skin extending to the very edge of the umbilical ring. The incision is carried through the center of the umbilical stalk, and each half of the stalk is detached from the underlying fascia and then deflected around the umbilical ring to either side to create a yin-yang appearance. It is advisable to use the instruments with low-profile back ends to avoid instrument collision at the abdominal wall. An additional 3 mm port can be added which is placed through a separate stab wound incision either at the pelvic brim or in the mid-epigastrium depending on the area of pathology. Use of this additional single-port maintains the triangulation at the area of interest without compromising the cosmetic benefit of the SILS. Surgeons considering SILS should first get sound with conventional MIS technique. A simple procedure with relatively easy dissection like appendectomy is a recommended SILS to start with such practice. Similar to any other procedure, a good assistant well versed with camera manipulation and coordination is an essential tool to complete the procedures using SILS technique.

Although this technique has generated a lot of excitement, true benefit of SILS seems to be mostly cosmetic when compared with the standard laparoscopic surgery. Additionally, there are many limitations to this technique. Larger single umbilical incisions may be associated with more pain, and it carries a higher risk for incisional hernias, and the technique requires expensive instrumentation specifically designed for SILS. Use of conventional laparoscopic instruments, with single-incision multiple-port technique to reduce the cost, has its inherent difficulties of having the camera and instruments all operating in line, causing instrument dueling and very little triangulation.

Role of Robotics in Pediatrics

With the advent of da Vinci robot, adult surgeons have readily incorporated this surgical technique into their practices. However, use of robot-assisted laparoscopic surgery (RALS) in the pediatric world has been looked upon with skepticism, and only a few centers are utilizing this approach, especially for small children. Several theoretical advantages of robotic technology include articulating instrumentation with increased degree of freedom, high-quality optical resolution, complete camera control by the operating surgeon, fine motor filtering, improved ergonomics for the surgeon, and precise instrument movement. However, it has been slow to gain popularity in pediatric world due to small available spaces, the time required for robotic assembly, and associated costs. Additionally, the pliable, thin abdominal wall in small children rarely is a hindrance to operate in locations like esophageal hiatus and pelvic cavity, areas considered difficult to reach in adults with standard laparoscopic instruments. As robotic technology improves with smaller instruments directed toward infants and neonates, the ability to apply this in smaller patients should expand, but its routine use, especially in neonates and small children, cannot be currently advocated.

Conclusion

MIS in infants and children is now the gold standard for most procedures in infants and children. The avoidance of a major laparotomy or thoracotomy has extreme and longterm benefits for infants and children with common surgical as well comlpex congenital disease. The continued improvemnt in techniques and devices that are right sized for smaller patients will continue to benefit this group of patients and make these techniques more widely accepted.

Cross-References

▶ Anorectal Malformations
▶ Congenital Diaphragmatic Hernia
▶ Congenital Malformations of the Lung
▶ Esophageal Atresia
▶ Fast-Track Pediatric Surgery
▶ Hirschsprung's Disease
▶ Infantile Hypertrophic Pyloric Stenosis
▶ Innovations in Minimally Invasive Surgery in Children

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