Innovations in Pediatric Surgery

Patrick M. Chesley, MD; and Patrick J. Javid, MD

The medical profession has seen tremendous growth in the past several decades, and recent advances in surgery have led to minimally invasive procedures and improved outcomes. Some of the best examples of technologic innovation in surgery can be found in the relatively young field of pediatric surgery. In this review, we describe several new techniques and novel surgical approaches to pediatric disease that continue to move the field of pediatric surgery forward. Pediatricians are well served to become more aware of these innovations, so that they might refer suitable patients as needed.

MINIMALLY INVASIVE PEDIATRIC SURGERY

Minimally invasive surgery in the adult population has been associated with shorter hospital courses, quicker return to activity, improved pain control, and smaller incisions for better cosmesis. As technology has improved and instruments have become smaller and more flexible, the use of laparoscopy for treatment of pediatric surgical disease has grown. Pediatric surgeons can now use minimally invasive approaches for more complex cases and are developing innovative techniques for common procedures.

One established area of minimally invasive pediatric surgery is in the treatment of pectus excavatum. In 1998, Nuss\(^1\) described a minimally invasive approach to the repair of pectus excavatum. In 1998, Nuss\(^1\) described a minimally invasive approach to the repair of pectus excavatum. In 1998, Nuss\(^1\) described a minimally invasive approach to the repair of pectus excavatum. In 1998, Nuss\(^1\) described a minimally invasive approach to the repair of pectus excavatum.

Figure 1. (A) The Nuss bar. (B) Preoperative photo of young male with pectus excavatum. (C) Postoperative photo detailing small lateral incisions and showing improvement in defect.

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steel or titanium bar posterior to the chest wall, thereby taking advantage of the pliability of the chest wall to correct the defect (see Figure 1, page 462). By making small incisions in the chest wall bilaterally, Nuss found that he could tunnel a curved bar between the sternum and the mediastinum. The bar is then rotated into position to apply pressure to the anterior chest wall and correct the defect. The bar is generally removed 2 to 3 years after the initial operation. The addition of a 5-mm thoracoscope to the procedure has enabled surgeons to visualize the passage of the bar across the chest, decreasing the theoretical risk of mediastinal injury.

This procedure greatly changed the treatment of pectus excavatum because previous techniques involved resection of the deformed costal cartilages through a long transverse incision and left children at risk for chest wall scarring and reduced exercise tolerance.

REPAIR OF PULMONARY MALFORMATIONS

As laparoscopic techniques have improved, pediatric surgeons have looked to treat more complex disease processes with a minimally invasive approach. One example of this trend can be found in the treatment of congenital pulmonary airway malformations (CPAMs), a broad category of lung masses that includes congenital cystic adenomatoid malformations and bronchopulmonary sequestration. These lesions can cause significant morbidity in children, including recurrent pneumonia and a long-term risk of malignancy.

Previously, these lesions were resected through a thoracotomy, a long and potentially painful incision through the intercostal space that has been associated with musculoskeletal deformities in the pediatric population. A thoracoscopic approach allows for smaller incisions on the order of millimeters instead of centimeters. In a thoracoscopic lobectomy for a CPAM, three to four 5-mm incisions are made throughout the child’s lateral chest wall, and the entire involved lobe can be removed through an incision as small as 1 to 2 cm. Albanese and Rothenberg have shown that the thoracoscopic approach to lobectomy for congenital pulmonary lesions in children is feasible and safe with no difference in the frequency of complications when compared with open thoracotomy. A recent meta-analysis showed a statistically significant decrease in postoperative hospital stays for lesions resected thoracoscopically, although this approach was associated with increased operative time. The study also found a trend toward fewer days of epidural anesthesia postoperatively in the thoracoscopic group.

MINIMALLY INVASIVE REPAIR OF CONGENITAL DISEASE OF THE ESOPHAGUS AND DIAPHRAGM

Other examples of more complex minimally invasive procedures in pediatric surgery include operative repair of congenital diaphragmatic hernia (CDH) (see Figure 2) and esophageal atresia with tracheoesophageal fistula (EA/TEF). Traditionally, surgeons have repaired CDH using a large open incision created in the subcostal region of the abdominal wall. Using thoracoscopy, pediatric surgeons can now perform a CDH repair using several 3- or 5-mm incisions along the lateral chest wall. As interest in this approach has increased, many have postulated that only those babies with favorable CDH characteristics would benefit from a thoracoscopic repair. Yang proposed two parameters as potential criteria that must be met to perform a thoracoscopic repair, including peak inspiratory pressure less than 24 mm Hg and tip of the NG tube within the abdomen. This likely corresponds to the size of the defect, with smaller defects being more favorable for tension-free repair. In addition, CDH babies on
extracorporeal Membrane Oxygenation (ECMO) are not considered candidates for thoracoscopic repair.

In 2011, Tsao et al. reviewed all cases within the CDH Registry and found that 8% of CDH repairs were performed using a minimally invasive approach. However, these minimally invasive repairs had an 8.8% recurrence rate compared with 2.6% for the open group. This high rate of recurrence was believed to be due to technical limitations of thoracoscopic surgery and that many of these procedures were the first of their kind. A more recent retrospective review of thoracoscopic CDH repairs at a single institution found an even higher recurrence rate of 23%. In this study of 54 neonates, the authors were unable to identify any risk factors associated with hernia recurrence. Although the use of minimally invasive techniques to repair CDH in babies is feasible and gaining traction, the high recurrence rate is prompting more study and discussion within the pediatric surgical community.

Thoracoscopic repair of EA/TEF is also becoming more common. The standard approach to definitive repair in a neonate is through a posterolateral thoracotomy in an extrapleural plane to reach the esophagus and trachea in the posterior mediastinum. An extrapleural dissection, in theory, avoids the complication of mediastinitis if an anastomotic leak occurs postoperatively. However, there can be significant long-term morbidity associated with a thoracotomy in children. Holcomb performed a multi-institution review of all patients who had undergone thorascopic repair for EA/TEF and found that the operation was not only feasible, but also had a complication rate similar to open repairs.

The noted advantages were the avoidance of a thoracotomy as well as the potential for improved visualization of mediastinal anatomy due to the magnification afforded by the laparoscope. Disadvantages to this technique include that the repair is transpleural, requires advanced laparoscopic skills, and necessitates prolonged single lung ventilation with collapse of the ipsilateral lung to provide operative space. Therefore, children with any sort of diminished respiratory reserve may not be ideal candidates.

LAPAROSCOPIC APPROACH TO COMMON AILMENTS

As the experience with laparoscopic surgery in children has increased, minimally invasive approaches to more com-
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mon procedures in pediatric surgery have evolved. Previously, percutaneous placement of a gastrostomy tube using endoscopy was the minimally invasive procedure of choice in children who required chronic enteral feeding access. However, a well-documented complication of the percutaneous endoscopic gastrostomy (PEG) is injury to the small or large bowel. These injuries occur because an endoscopist cannot know if the bowel is situated between the stomach and the abdominal wall when placing the percutaneous tube. In the laparoscopic method, a small camera is inserted through a 5-mm incision at the umbilicus, the stomach is visualized, and another 5-mm incision is made at the desired gastrostomy site. A laparoscopic instrument is then inserted, and the stomach is pulled to the abdominal wall, thus preventing inadvertent injury to the colon. The stomach can also be sutured to the abdominal wall fascia using this technique, thereby securing the gastrostomy in case the tube is dislodged in the early postoperative period. When compared retrospectively, the laparoscopic approach has been associated with a 50% reduction in the incidence of complications compared with PEG. A final advantage of the laparoscopic approach is that a primary button can be placed instead of a long feeding tube. Given these data, many pediatric surgeons prefer the laparoscopic approach over the endoscopic approach.

Laparoscopic pyloromyotomy has shown improved outcomes with decreased time to full feeds and fewer episodes of postoperative emesis.

An additional laparoscopic procedure that has gained widespread acceptance in the field of pediatric surgery is the laparoscopic pyloromyotomy to treat hypertrophic pyloric stenosis. Instead of a right upper quadrant or periumbilical incision, the laparoscopic pyloromyotomy uses three separate 2- to 3-mm openings in the umbilicus and lateral abdominal wall. Compared with the open technique, laparoscopic pyloromyotomy has shown improved outcomes with decreased time to full feeds, fewer episodes of postoperative emesis, lower requirement of postoperative analgesia, and improved cosmesis. Although a meta-analysis found the laparoscopic approach to be associated with an increased risk of incomplete myotomy and mucosal perforation, a recent randomized, prospective, controlled study did not find a difference in the incidence of intraoperative complications between the two approaches.

The subcutaneous endoscopic assisted ligation of the hernia sac (SEAL) was developed to provide a minimally invasive approach to inguinal hernia repair to reduce postoperative pain, provide an opportunity to examine the contralateral side, and avoid making a larger groin incision. This procedure involves introduction of the laparoscope through the umbilicus. A small skin nick is then made over the lateral side of the internal ring and a suture is passed transabdominally around the internal ring. In this fashion, the surgeon can manipulate the direction of the needle using real-
time guidance from the laparoscope and avoid injury to the vas deferens and the gonadal vessels while ligating the hernia sac. An important disadvantage to this approach is the rate of recurrence, which is still approximately 4% in the SEAL technique compared with 1% to 2% using the open technique.17

To develop an even less invasive approach to operative intervention, pediatric surgeons are now attempting single-incision laparoscopy surgery (SILS). In these procedures, a slightly larger incision is made at the umbilicus, and a single incision port that has several different working trocars is placed. Appendectomies, cholecystectomies, and even splenectomies have been performed using this technique.18 The most significant disadvantage to this approach is the limited degree of freedom created by having one operating port that does not allow triangulation of instruments in the target space. This has led to a steep learning curve and increased operating room time. Although attempts have been made to improve this technique by using angled laparoscopes, the single site field is still in development.

USE OF ROBOTICS

Although laparoscopic surgery is clearly beneficial for many procedures, it has its operational limitations. The image displayed is 2-D and the instrument ports can limit the range of motion. The field of robotic surgery has offered potential solutions to these problems. Initially designed for the military to allow a surgeon to perform an operation from a satellite facility, advantages of this new technology were quickly realized and robotic surgery now provides a safe, minimally invasive alternative in many complex cases (see Figure 3, page 464).

Two main advantages with the robot include the operating console that displays a 3-D image using left and right cameras and instruments that articulate at their end, allowing more delicate movements. The robotic approach also provides resistance to a surgeon’s tremor and creates microscopic movements by scaling the ratio of actual surgeon movement to the movement of the instrument. Many complicated procedures have been performed successfully using robotic surgery in children, including Ladd’s procedure for malrotation, Nissen fundoplication, lung resection for congenital lung lesions, and thymectomy.19 Although this newer technology is finding applications within pediatric surgery, it has not yet been shown to be superior to laparoscopic approaches. As surgeons gain experience with this technology and it becomes more widely accepted, it is not unreasonable that robotic surgery may be fully accepted as a minimally invasive alternative in the most complex pediatric surgical cases.

BOWEL LENGTHENING IN INTESTINAL FAILURE

Intestinal failure in children is frequently associated with disease processes that require early resection of a large segment of bowel in the young infant. This can leave the child with dramatically decreased bowel length and anatomic malabsorption, a state referred to as short bowel syndrome (SBS). Several etiologies frequently associated with SBS are necrotizing enterocolitis, gastroschisis, intestinal atresia, midgut volvulus, and long segment Hirschprung’s disease.20 Depending on the remaining bowel length and its functional status,
these infants may need nutritional supplementation in the form of parenteral nutrition and enteral feeds for years.20 As our knowledge of pediatric intestinal failure has progressed, a significant improvement in long-term survival has been demonstrated during the past decade. One of the most important advances has been the finding that early referral to a multidisciplinary intestinal failure program significantly decreases mortality.21

One novel approach to increase bowel length in children with SBS is the serial transverse enteroplasty (STEP) bowel-lengthening procedure (see Figure 4, page 466). As bowel adaptation occurs, the intestine routinely dilates creating a scenario in which the effectiveness of peristalsis is greatly reduced. In addition, dilated bowel is at risk for the development of bacterial overgrowth. The STEP procedure was developed to improve bowel function by tapering the bowel through serial applications of a surgical stapler along the longitudinal axis of the mesentery on alternating sides of the bowel.22 This creates a longer, narrower bowel with an increased luminal transit time for improved absorption. The STEP procedure has been shown to enhance bowel function and improve tolerance of enteral nutrition.23 The procedure can be repeated if necessary, an improvement over the classic Bianchi procedure, which involved a more complex reconstruction of bowel and its mesentery. Recently, an international Web-based outcomes registry has been created to collect and analyze long-term data from the STEP procedure,24 and long-term outcomes have been favorable.

FETAL SURGERY

The diagnosis of many congenital anomalies can now be made in the fetus with the use of prenatal ultrasound. With improvements in maternal anesthesia as well as tocolytic therapy, the opportunity exists for fetal surgeons to intervene and provide life-saving therapy prior to delivery. Initially, due to concerns of uterine hemorrhage, as well as increased risk of premature labor, many of these procedures involve minimally invasive fetoscopic techniques, such as tracheal occlusion for congenital diaphragmatic hernia, cystoscopy for decompression of urinary obstruction, and laser ablation of placental vessels in twin-twin syndrome.25 However, newer techniques have been developed that allow open fetal surgery to be performed.

A noteworthy indication for fetal surgical intervention is the development of non-immune hydrops, which presents as serous fluid accumulation in more than one body cavity.26 Non-immune hydrops and subsequent heart failure can be caused by anomalies that compress mediastinal vascular structures or highly vascular tumors that lead to high cardiac output. These lesions are followed throughout pregnancy and can be treated with steroids, fetoscopic thoracentry, open surgical resection, or ex utero intrapartum resection of the mass depending on the etiology of the lesion and the gestation age of the fetus.28 In the setting of fetal lung malformations, maternal steroids are believed to induce maturation of lung tissue, improve pulmonary compliance, and have been associated with resolution of hydrops fetalis in a small series.27

The major source of morbidity in CDH children is pulmonary hypoplasia, and the previously held belief was that occlusion of the trachea would stop the efflux of pulmonary fluid and therefore stimulate pulmonary growth.28 Initially, this procedure showed great promise, although a randomized controlled trial was unable to show a mortality benefit and the procedure is still considered experimental.28 However, to reverse the tracheal occlusion at birth, ex utero intrapartum therapy (EXIT) was developed.29 This interesting advance in fetal surgery allows delivery of the baby from the uterus while maintaining placental support. The procedure is performed by first creating a hysterotomy, partially exposing the baby, gaining peripheral vascular access, and intubating the infant while remaining on placental support. Procedures such as resection of pulmonary lesions, excision of head and neck tumors, and creation of surgical airways can then be performed in a more stable environment prior to discontinuing placental support and completion of the delivery.30

GASTROSCHEISIS

The previous treatment options for this increasingly common abdominal wall defect have included primary closure and the placement of a silastic silo that is sequentially tightened, reducing abdominal contents and allowing the opportunity to perform a delayed primary closure of the abdomen. However, a recent development occurred after the observation that a child was able to heal this defect through secondary intention. The plastic closure for gastroschisis was developed by reducing the abdominal contents immediately after birth, wrapping the native umbilical cord into the defect, placing a clear plastic dressing over the umbilical cord, and then allowing closure by secondary intention and epithelization26 (see Figure 5, page 467). The primary advantages of this technique are that it maintains lower abdominal pressure while not losing abdominal domain, produces a cosmetically acceptable result, and can be performed at the bedside in the neonatal intensive care unit. A retrospective review of this
technique found infants were extubated sooner than babies undergoing the traditional closure. Interestingly, their time to full enteral feeds and discharge was not statistically different.32

BARIATRICS

The obesity epidemic continues to be one of the greatest health risks faced in the present time. In the adult population, outcomes with bariatric surgery have been well documented; many studies show significant reductions in the comorbidities associated with obesity, and some patients can experience reversal of obesity-related disease states such as diabetes. As bariatric surgery in adults has become more widely accepted, its role in the pediatric population is actively being discussed. Although there is no consensus at this time, some have suggested the use of bariatric surgery in adolescents with a BMI of greater than 40 and any comorbidities related to obesity or any adolescent with a BMI of greater than 50.33 Pediatric candidates for bariatric procedures must fail conservative weight-loss strategies before being considered for surgical options.

The most common procedure performed in adults and children is the Roux-en-Y gastric bypass. This procedure has both a restrictive and malabsorptive component. A small pouch is created at the superior portion of the stomach. The jejunum is then divided distal to the ligament of Treitz and the downstream portion of the jejunum is brought up to join the newly created gastric pouch. The proximal small bowel is then reattached to the mid-jejunum distal to the anastomosis with the stomach. Digestive contents are able to mix with meals in this common channel, after a portion of small intestine has been bypassed. A single center followed 36 adolescents for 1 year after they underwent gastric bypass and were able to show a reduction of 20 units in their BMI.34 Complications in these patients ranged from diarrhea and dehydration, to dumping syndrome, and internal hernia and beriberi. In this cohort, 22 patients did not experience any complications. Although these results are promising, the long-term outcomes of such an invasive intervention have yet to be determined, especially regarding patients’ nutritional status. Research is being actively conducted to better understand how bariatric surgery affects children and to develop consensus guidelines to better address the treatment of this complex issue.

CONCLUSION

As our knowledge continues to expand and we gain technical experience in the surgical management of pediatric disease, the field of pediatric surgery will continue to evolve. The future in pediatric surgery holds promise for the improvement of minimally invasive techniques in increasing complex diagnoses from infancy to young adulthood. ■

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23. Javid P, Kim HB, Duggan CP, Jaksic T. Serial transverse enteroplasty is associated with successful short-term outcomes in infants with...


Erratum:

In the August Issue of *Pediatric Annals* (Vol. 42, Issue 8), in the article by Daniel P. Boyle, MD and John P. Flaherty, MD, “Adult Immunization and Its Impact on Children”, in the Table, it currently states that at least three doses should be given to adults for mumps. Instead, it should say, “At least two doses.” The authors regret the error. Search the author names to read the corrected article online at Healio.com/Pediatrics.

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