



Reviews

Minimally Invasive Surgery in Childhood: Current Status

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Key words: pediatric laparoscopy, pediatric thoracoscopy, minimally invasive surgery

IMAJ 2000;2:377-381

With the development of innovative technologies in medicine, minimally invasive surgical procedures have been extended to increasingly younger children. Procedures once entrusted entirely to laparotomy can now be accomplished on an outpatient basis or at least with shorter hospitalization, and with more rapid recovery and less pain. Removal of the gallbladder and acute appendix, de-torsion of a twisted adnexa, abdominal exploration, and thoracoscopic lung biopsy and sympathectomy are now well-established endoscopic procedures in childhood. Advanced MIS includes fundoplication, pull-through for Hirschsprung's disease, nephrectomy and splenectomy. Important advances have also been made in the use of laparoscopy for both the diagnosis and treatment of a range of endocrinological disorders in children and adolescents. The aim of the present review is to critically summarize the current status of MIS in pediatric practice.

The laparoscopic technique

In children, laparoscopic procedures are performed under general anesthesia and endotracheal intubation with instruments of 2–10 mm in diameter and varying lens configurations. The lately developed mini-instruments are particularly suitable for both diagnostic and operative procedures in the pediatric population. Prophylactic antibiotics may be administered preoperatively to minimize infection at port sites. Stomachs and bladders are emptied immediately before and during surgery. Since the abdominal wall is thin and elastic in children, it is prone to entry of a Veress needle or port into the subcutaneous space rather than the peritoneal cavity. The reduced margin of safety in children compared to adults also increases the risk of injury to the abdominal viscera and major vessels during initial and secondary port placement. Therefore, even if a Veress needle can be used to establish a pneumoperitoneum, most pediatric surgeons prefer to insert the ports — at least the first one — under direct visualization. Insufflation of carbon dioxide is performed at 0.5–2 L/min. The total volume varies

with age; end-point pressure limits are 6–8 mmHg in infants, 8–10 mmHg in children, and 10–12 mmHg in older adolescents and adults. On completion of the procedure, the port sites are re-approximated at the skin site. Fascia closure is recommended for ports larger than 5 mm to lower the likelihood of herniation. Children often have fewer complaints of shoulder pain than adults. However, every effort should be made to be as thorough as possible in expulsion of the insufflated gas.

Contraindications for MIS surgery include coagulopathies, cellulitis, and abscesses of the abdominal or thoracic wall. Previous abdominal surgery, pleural adhesions, severe cardiorespiratory compromise and increased intracranial pressure are considered relative contraindications because of the possible hemodynamic changes associated with increased carbon dioxide absorption, elevation of the diaphragm and decreased venous return [1]. The inability to directly palpate the organ surface is one of the shortcomings of MIS and should be taken into account when deciding on the surgical approach.

Abdominal surgery Appendectomy

One of the most extensive applications of laparoscopy in pediatrics is in the treatment of appendicitis, although many arguments have been proposed against the use of this approach [2]. The collected data from several series of adults and of children suggest no major differences in the results of appendectomy using the open or the laparoscopic technique. Although there are no major advantages to the laparoscopic technique, neither are there any significant disadvantages. The operating time may be slightly longer with the laparoscopic approach, but this is compensated by less postoperative discomfort, quicker recuperation (a few hours to a few days), and earlier return to normal activities [2,3]. The cosmetic result is also better.

el Ghoneimi et al. [4] reported their experience with 1,379 cases of laparoscopic appendectomies in children (average age 10 years, range 2–16). The incidence of minor intraoperative events was 2.1%, and the postoperative

MIS = minimally invasive surgery

complication rate 1.5%. Less than 1% of the patients required a subsequent laparotomy or an additional laparoscopic procedure, and there were no deaths. The children were discharged after an average 2 day hospital stay and returned to unrestricted activities within a week of surgery. The authors concluded that laparoscopic appendectomy enables easy and rapid localization of the appendix, exploration of the whole abdominal cavity, and complete lavage of the contaminated peritoneal cavity. In addition, the frequency of intraperitoneal abscesses and postoperative adhesions is reduced. Furthermore, in a retrospective study of 403 children with appendicitis, half of whom underwent laparoscopic appendectomy, Varlet et al. [5] noted that there were many more postoperative complications with open appendectomy (10.8% vs. 1.5%, $P < 0.0001$). The nature of the complications also appeared to differ [3–6]. Open appendectomy was associated with more wound-related infections than intraperitoneal abscesses; the opposite was true for laparoscopic surgery.

Cholecystectomy

The results of laparoscopic cholecystectomy in children are similar to those in adults. Holcomb et al. [7] reviewed their experience with 26 laparoscopic cholecystectomies in children, including 5 with acute cholecystitis who underwent cholangiography. They concluded that laparoscopic cholecystectomy in children is safe and as cost-effective as in adults. Vinograd and his group [8] also reported on the efficacy and safety of the procedure for patients under 2 years of age. Like laparoscopic appendectomy, laparoscopic cholecystectomy may be beneficial in the management of obese patients [9].

Excision of Meckel's diverticulum

Meckel's diverticulum in children can be easily managed with MIS, as reported by Schier et al. [10].

Abdominal exploration

In adolescents, laparoscopic abdominal exploration is used for the diagnosis of chronic abdominal or pelvic pain and/or dysmenorrhea or primary amenorrhea. The most common finding is endometriosis. Reproductive tract endometriosis may be associated with müllerian developmental defects, such as imperforate hymen, vaginal septum, hematocolpos, hematometra, uterine anomalies, and associated urinary tract abnormalities such as unilateral renal agenesis. Endometriosis may also be associated with "smooth muscle metaplasia," hemangiomas, leiomyomata, and adenomyosis of the gastrointestinal tract [11].

Creatas et al. [12] reported on their experience with laparoscopy in 40 girls aged 14–19 years. Of the 21 patients who presented with primary amenorrhea, laparoscopy revealed Rokitanski-Kuster-Hauser syndrome in 12, hematocolpos-hematometra in 4, polycystic ovarian disease in 2, late onset of puberty in 2, and gonadal dysgenesis in 1. Of the 12 patients with pelvic pain, laparoscopy showed normal genitalia in 6, endometriosis in 2, infection in 2, and fibroma and ovarian torsion in one each.

Pyloromyotomy

Fujimoto's group of researchers [13] recently compared laparoscopic pyloromyotomy with open transumbilical pyloromyotomy. They found that the time taken to reach full feeding was significantly shorter (38 vs. 64 hours) and the incidence of postoperative vomiting significantly lower (3% vs. 25%) in the laparoscopic than in the open group. The authors claim that the laparoscopic approach was less traumatic, because in the open technique — particularly with the transumbilical approach — the manipulation of and tension placed on the pylorus in order to expose it through the umbilical wound can produce edema in the muscle layer, mucosal swelling, and occasionally, serosal laceration. However, laparoscopic pyloromyotomy has still not gained acceptance among pediatric surgeons. Opponents contend that excellent results can also be achieved with pyloromyotomy through a small skin incision, with shorter operating time, less instrumentation and low morbidity rate.

Fundoplication

Laparoscopic fundoplication is currently widely performed in children. Tovar et al. [14] and Rothenberg [15] reported similar efficacy and failure rates for open and laparoscopic fundoplication after a 1–2 year follow-up. Bufo's team [16] concluded that the laparoscopy procedure has a longer operative time but requires a shorter hospitalization and is associated with fewer late complications.

Malrotation

The Ladd laparoscopic procedure for malrotation has been used in both infants and children with good results [17].

Ambiguous genitalia

Laparoscopy can be used as part of the diagnosis and treatment of intersex patients of all ages. Most patients with ambiguous genitalia, particularly impalpable gonads, are assigned a female gender until virilization and phallic erections occur at puberty. In the study of Yu et al. [18], laparoscopic gonadectomy was performed in three patients aged 16–18 years with testicular feminization syndrome, 17 β -hydroxysteroid dehydrogenase deficiency, and 5-reductase deficiency with non-palpable gonads respectively. They suggested that in affected individuals raised as females, laparoscopic assessment of the pelvic configuration and detection of intraabdominal gonads can lead to earlier gonadectomy, thereby avoiding later virilization at puberty. In individuals raised as males or reassigned a male gender (for example, those who are androgen responsive with 5-reductase and 17 β -hydroxysteroid dehydrogenase deficiency), gonadal preservation may be performed in combination with masculinizing genitoplasty and removal of the inappropriate müllerian structures.

Adnexal de-torsion

Torsion of the fallopian tube and/or ovary should be suspected in patients with acute onset of unilateral lower abdominal pain, often radiating downwards, followed by intermittent recurrences over time [19]. Color Doppler ultrasonography is an excellent diagnostic modality [20].

Intraoperatively, the contralateral adnexa should also be assessed. According to Davis and Feins [21] and Grunewald et al. [22], contralateral oophoropexy should be considered in the rare cases of asynchronous torsion of a normal adnexum. Torsion is frequently associated with an adnexal mass, and this should also be investigated. Management consists of untwisting the adnexa and confirmation by visualization. The reappearance of viability in the de-torted adnexa indicates preservation.

Splenectomy

Splenectomy may be necessary for some hematological disorders, such as hereditary spherocytosis, idiopathic thrombocytopenic purpura, and sickle cell disease, to avoid complications of clinically severe disease. Laparoscopic splenectomy can be performed safely in children despite the risk of overlooking accessory spleens, which is one of the major arguments against this approach. Another controversial technical aspect is the size of the spleens than can be excised. This procedure cannot be performed for a spleen larger than 500 g. In a recently reported series of 63 children (average age 7 years) who had undergone laparoscopic splenectomy for hematological disease, operating time was longer than for open splenectomy but narcotic requirement was less and the length of hospitalization was shorter [23].

Hirschsprung's disease

In 1993, Georgeson and co-workers [24] described a single-stage primary laparoscopic pull-through procedure for infants with Hirschsprung's disease. This approach was used in 75 children (ranging from newborns to 8 year olds) by Jona's group [25], who recommended it as the sole procedure for neonates and infants with long-segment disease.

Thoracic surgery

The team headed by Mattioli [26] recently evaluated their experience with 39 pediatric patients who underwent surgery between 1993 and 1996 for lung parenchymal disorders. Twenty-six had benign lesions and 13 had malignancies, specifically lobar emphysema (n=5), pulmonary fibrosis or bronchiolitis (n=7), cystic dysplasia (n=9), and abscesses (n=5), including primary bronchial tumors (n=2) and metastases (n=11). The authors compared the results of treatment with video-assisted thoracoscopic surgery or the muscle-sparing approach with those for open procedures, comparing also mechanical staplers with conventional suturing. They found that video-assisted thoracoscopic surgery, the muscle-sparing approach, and mechanical staplers are important new modifications of the classical operative technique and principles of lung resection. The minimally invasive approach associated with mini-thoracotomy was particularly beneficial for patients with reduced oxygen saturation due to ventilatory and gas exchange problems. Mechanical suturing was especially advantageous in decreasing anesthetic time and reducing the risk of dehiscence.

Hyperhidrosis

In recent years, thoracoscopic upper thoracic sympathectomy has become the procedure of choice for palmar hyperhidrosis. Prior to the report of Kux [27] in 1977, various conventional surgical approaches had been used to interrupt the sympathetic supply to the palmar and axillary area. Kao et al. [28] described excellent results for thoracoscopic laser sympathectomy in 40 children under age 16. More recently, Cohen's team [29] reported on their experience with 223 pediatric, adolescent and adult patients: the operative time for the bilateral procedure was 30 minutes, no conversion to open technique was necessary, and there were no intraoperative complications. Moreover, immediate and permanent relief of palmar sweating was noted in 219 patients (98.2%).

Groin surgery

- *Inguinal herniotomy:* Infants and children with unilateral symptomatic inguinal hernias can now undergo safe and accurate exploration of the contralateral groin by means of the laparoscopic technique. The symptomatic side is explored in the normal open fashion, and the hernia sac is dissected free and divided. A 70° telescope is passed into the peritoneal cavity through the cannula to inspect the peritoneal aspect of the contralateral internal inguinal ring. Holcomb [30] recently reported that among 487 patients in whom laparoscopy did not find a contralateral patent processus vaginalis, two boys and one girl later returned with symptomatic contralateral hernia, yielding a false negative rate of 0.61%. There were no complications related to the laparoscopy or the hernia repair. In a recent meta-analysis of the usefulness of laparoscopy in the diagnosis of contralateral inguinal hernia in 964 patients from 9 different series [31] (mean age 2 years and 4 months, range 0 months to 18 years), including premature infants, sensitivity was found to be 99.4% and specificity 99.5%. Laparoscopy added an average of 6 minutes to the surgical time and was proven safe. The authors concluded that laparoscopy may be considered the ideal tool for intraoperative diagnosis of a contralateral patent processus vaginalis, but they did not support the use of routine laparoscopic exploration of the contralateral groin. They recommend the laparoscopic assessment for children with risk factors of hernia, such as increased intraabdominal pressure and connective tissue disorders, or when the clinical evidence is insufficient for a decision regarding surgical intervention.

- *Non-palpable undescended testis:* In patients in whom one or both testes are not palpable, laparoscopy is indicated to locate the testicle and to determine the orchiopexy approach. Findings may include the following: a) The testicular vessels end blind before they reach the internal ring, making inguinal exploration unnecessary. b) The testicular vessels enter the inguinal canal, so that a testicular remnant or perhaps a small testis may be found in the inguinal region, necessitating inguinal exploration. c) The testis is normal but located in the proximity of an open internal ring, which makes it non-palpable on manual

examination; inguinal exploration with standard orchiopexy is performed in the majority of such cases. d) The testis is viable but situated in a high intraabdominal site, precluding one-stage orchiopexy, and preliminary clipping of the spermatic vessels (first stage Fowler-Stephens procedure) can be performed. e) The testis is atretic and located intraabdominally, necessitating laparoscopic orchiectomy. Studies have shown that in patients with a unilateral non-palpable testis, laparoscopy reveals the intact spermatic cord entering the internal ring in 57–70% of cases, mandating inguinal exploration in two-thirds of them [32,33]. Therefore, we suggest that in this subgroup, since laparoscopy alone is sufficient in only one-third of patients, inguinal exploration should be the first-line diagnostic and curative procedure. For testicles found to be located intraabdominally on diagnostic laparoscopy, Gheiler et al. [34] recommended the Jones approach [35] instead of the standard extended inguinal approach. With the Jones approach, the testicle and spermatic cord are dissected preperitoneally. The testicle is brought down immediately adjacent to the pubic tubercle and anchored in the scrotum with the Dartos pouch technique. Using this approach, Gheiler's group [34] were able to avoid spermatic vessel ligation in all but one of 19 patients (95% success rate); by comparison, all their historical controls required spermatic vessel ligation, with only a 70% success rate. Esposito and Garipoli [36] used laparoscopic orchiopexy with the two-step Fowler-Stephens procedure: laparoscopic division of the vessels followed 6–12 months later by a second-stage laparoscopic procedure. All testicles were successfully placed in the scrotum, with a more than 95% success rate. Centers that perform minimally invasive surgery report that both primary and two-stage laparoscopic orchiopexy are as effective as open surgery and perhaps even more advantageous. Considering that MIS is still not widely performed by pediatric surgeons, we expect that in patients with undescended testicles, this modality will eventually take precedence but will not entirely replace open techniques.

Tumor staging

Minimally invasive examination of the abdomen or thoracic cavity in children with malignant disease can provide tissue for diagnosis and staging, as well as complement data obtained by imaging modalities on spread and resectability. Laparoscopy has been found to be superior to computed tomography for the staging and evaluation of neoplasms that seed via peritoneal implants, and for assessing unexplained ascites [37].

Second-look operations can be undertaken laparoscopically to evaluate the response to chemotherapy in patients with neuroblastoma, germ cell tumors, and non-Hodgkin's lymphoma. Also, tissue biopsies from the liver, lymph node, or residual tumors can be obtained by laparoscopy. Splenectomy, when indicated, can also be done laparoscopically [38].

When radiotherapy to the lower abdomen and pelvis are administered to children, oophoropexy is usually performed as well. Abdominal exploration by either laparotomy or

laparoscopy will alter the clinical staging for about 30–40% of children. In the majority, the stage will be upgraded, mainly from stage 1 or 2 to stage 3 or 4 [39].

Laparoscopy can replace laparotomy to minimize post-operative pulmonary complications and intraabdominal adhesions, yielding a shorter interval to initiation of definitive therapy. Saenz et al. [40] recently reported their experience with 84 pediatric and young adult oncology patients who underwent 93 minimal access procedures. The laparoscopic procedures included liver biopsy (n=21), diagnostic tumor biopsy (n=13), lymph node biopsy (n=4), cholecystectomy (n=4), oophoropexy (n=3), and kidney biopsy (n=1); the median hospital stay was 2 days (range 1–14). Thoracoscopic procedures included diagnostic lung biopsy (n=22), mediastinal mass biopsy or resection (n=4), pleural biopsy (n=5), and pleurodesis (n=4); median hospital stay was 4 days (range 2–35 days). The authors concluded that MIS is safe and effective and enables an earlier initiation of adjuvant therapy.

Conclusions

Endoscopic surgery is associated with reduced morbidity, shorter hospital stay, greater safety and less pain than achieved with many standard procedures, and may therefore be the ideal tool for the treatment of numerous conditions in childhood. Already today, laparoscopic surgery has become the optimal approach for the following procedures: cholecystectomy, fundoplication, and thoracic sympathectomy for hyperhidrosis, lung and mediastinal biopsies and inspection. It also plays an important role in defining the internal gonadal structures in intersex patients, as well as in the performance of gonadectomy, when indicated. The laparoscopic approach to ovarian lesions is effective and safe for diagnosis and definitive therapy. This method should be the first diagnostic approach for bilateral non-palpable undescended testicles. For unilateral non-palpable undescended testis, groin exploration seems to be the first logical step. MIS has also proven to be efficient in the investigation of chronic abdominal and pelvic pain.

Nevertheless, since further experience is needed before advanced endoscopic surgery is accepted as the golden standard worldwide, this modality is currently limited to major centers with a large number of patients. This is especially true for the treatment of Hirschsprung's disease, fundoplication, splenectomy and nephrectomy. The experience of the next few years will be crucial for reaching operative conclusions. We will surely be witness to the integration of many procedures that will replace conventional surgery and other interventions whose use will be sporadic or even contraindicated. Finally, we expect that the introduction of mini-instruments and robotics in endoscopic surgery will open horizons that are still beyond the limits of our imagination.

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Capsule



Bacteria adaptation in cystic fibrosis

Cystic fibrosis patients develop chronic airway infections with *Pseudomonas aeruginosa*. *P. aeruginosa* synthesized lipopolysaccharide with a variety of penta- and hexa-acylated lipid A structures under different environmental conditions. In a CF patient *P. aeruginosa* synthesized lipopolysaccharide with specific lipid A structures, indicating unique recognition of the CF airway environment. CF-

specific lipid A forms containing palmitate and amino-arabinose were associated with resistance to cationic antimicrobial peptides and increased inflammatory responses, suggesting their involvement in airway disease.

Science 1999;286:1561