



Minimally invasive surgery in the neonate

Joachim F. Kuebler, Benno M. Ure*

Department of Pediatric Surgery, Hannover Medical School, Carl-Neuberg-Str. 1, 30625 Hannover, Germany

S U M M A R Y

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The advent of minimally invasive surgical techniques in the neonate has been delayed due to the limited working space and the unique physiology of the newborn. In the last decade, with the introduction of new instruments and techniques, many of the initial problems have been solved making minimally invasive surgery feasible for a variety of indications in the neonate and a favored approach in specialized centers around the world. Although an increasing number of reports document the feasibility of this exciting technique, data demonstrating its benefit compared to conventional surgery is limited. This review focuses on recent developments in minimally invasive surgery in neonates and the evidence for its use.

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1. Introduction

In the last four decades, minimally invasive endoscopic surgical techniques have proven beneficial for a wide range of indications in abdominal and thoracic surgery in children. However, their application in neonates was delayed by technical limitations, such as the size of the instruments. In the last 10–15 years with suitably small, high quality instruments becoming available, minimally invasive procedures have also been performed in the neonate. Nonetheless, up to now, minimally invasive neonatal surgery has been limited to specialized centers, the incidence is low and the evidence of its benefit is scarce.¹ In a retrospective multicenter study, Kalfa et al. analyzed all procedures performed in infants aged <28 days in seven European university departments during the 12-year period from 1993 to 2005.² There were a total of 245 laparoscopic or thoracoscopic procedures performed, i.e. an average of about three cases per center and year. This review deals with the recent developments of minimally invasive surgery in neonates and the most common indications today.

2. Physiologic aspects of neonatal endoscopic surgery

The neonatal period is a crucial time of adaptation characterized by changes in organ and immune functions, making the neonate unique in its physiology. There are limited data regarding the

physiologic response of the neonate to the effects of laparoscopy, thoracoscopy and the insufflation of CO₂. Nonetheless, clinical and experimental data point towards a higher sensitivity of the neonate and potential side-effects of the peritoneal CO₂ insufflation.^{3–5} In their multicenter retrospective analysis, Kalfa et al. noted that 61% of the reported complications in neonatal endoscopic surgery, such as desaturation, hypotension, hypercapnia, hypothermia, and metabolic acidosis were related to the anesthesia.² Their observation that especially thoracoscopic procedures tend to cause unwanted physiologic side-effects is supported by other authors.^{1,6,7} Experimental data have shown an increased CO₂ absorbance in the young⁸ and a higher sensitivity of the neonatal cardiovascular system.⁴ Nonetheless, clinical experience indicates a good adaptation of the neonate to incrementally increased pressures of a CO₂ pneumothorax and peritoneum and experimental data suggest that moderate pressure insufflation does not cause any significant drop of capillary perfusion in splanchnic organs.^{9–11} Renal perfusion and urine production appear to be more sensitive, with the majority of infants developing temporary anuria during laparoscopic procedures, potentially complicating fluid balance.¹² It is important to note that besides the insufflation, the desufflation of the pneumoperitoneum and the concomitant decrease in intra-abdominal pressure can impair the circulation.^{13,14} Therefore, intensive postoperative monitoring is warranted. One aspect of the neonatal circulation is the persistence of the fetal circulation with patent umbilical vessels and a potential right-to-left shunt. This makes neonates susceptible to severe forms of inadvertent gas embolism, which has been described in several cases.^{15–17}

* Corresponding author. Tel.: +49 511 532 9260; fax: +49 511 532 9059.
E-mail address: kuebler.joachim@mh-hannover.de (J.F. Kuebler).

3. Laparoscopy in the neonate

3.1. Pyloromyotomy

One of the most common indications for endoscopic surgery in the neonatal period is the laparoscopic pyloromyotomy for hypertrophic pyloric stenosis. First described by Alain et al. in 1991, it is usually performed using a three-port technique with 3 mm instruments.¹⁸ It is well known that this operation is associated with a steep learning curve.^{19–21} Nonetheless, several randomized prospective studies comparing laparoscopic to open pyloromyotomy failed to show a significant increase in intraoperative or postoperative complications.^{22–24} Moreover, the most recent multi-institutional double-blinded prospective randomized trial was stopped early because of slight, but significant advantages of the laparoscopic compared to the open technique with regard to time to full oral feeds and hospital stay.²⁵ It appears that this operation is associated with potential complications, especially intraoperative perforation and inadequate pyloromyotomy, and this might not be adequately represented in some of the studies due to the varying experience of the surgeons.^{26–29} With perioperative complication rates in reported series as high as 20%, experience appears to be an important factor in performing this technique safely.²¹

3.2. Ovarian cysts

Cystic lesions of the ovary are a common finding in the neonate. With increasing size, these cysts are associated with an increased risk of ovarian torsion. Although there is no consensus on the exact diameter of a cyst that warrants surgical intervention, it is generally accepted that cysts larger than 4–5 cm should be treated. Among the potential therapeutic interventions, such as aspiration or open surgery, laparoscopic treatment, first described by Waldschmidt et al.³⁰ and in a series by van der Zee et al.³¹ has proven its efficacy, and several modifications to the original method have been described.^{32–34} One advantage of the laparoscopic approach is its flexibility and diagnostic value. Besides treatment of uncomplicated cysts by decapsulation or aspiration under view, it also allows adequate management after adnexal torsion, either via resection of the necrotic ovary or by detorsion.^{35–37} Ultrasound-guided aspiration of a presumed ovarian cyst might be even less traumatic than laparoscopy, but it includes the risk of misdiagnosis. Rare cases of intestinal duplication or other cystic structures might be sonographically mimicking an ovarian cyst, and simple puncture has been shown to be potentially associated with grave consequences.³⁸

3.3. Fundoplication

Numerous articles suggest the potential benefits of laparoscopic versus conventional fundoplication in infants and children, such as reduced length of hospital stay.^{39,40} The data regarding fundoplication in neonatal patients is scarce. Retrospective studies including small infants and neonates suggest that, in expert hands, laparoscopic fundoplication can also be performed in the very small, neonatal patient with low morbidity and a low rate of complications.^{10,41} In accordance with these studies, Thatch et al.⁴² reported a retrospective comparison of open and laparoscopic fundoplication performed in patients of the neonatal intensive care unit. They observed a high efficacy and low rate of complications for both approaches. Regarding the different techniques, Nissen fundoplication appears to be most common, but others, such as the Toupet or Thal technique, have also been described.^{43,44}

3.4. Duodenal atresia

The successful laparoscopic repair of a duodenal atresia by duodenoduodenostomy in a newborn was first introduced by Bax et al. in 2001.⁴⁵ After reports of other successful cases, this procedure has been introduced in specialized centers.^{2,10,46,47} Few series have been published so far. In their retrospective comparison of laparoscopic versus open duodenoduodenostomy, Spilde et al.⁴⁸ observed no intraoperative complications and an excellent outcome that equalled the open group. Moreover, time to full feeds and hospital stay were shorter in the laparoscopic group. They point out that their suturing technique using nitinal u-clips was important for the low morbidity rate. Similar outcomes were reported by Kay et al.⁴⁹ using traditional intracorporeal suturing techniques. After the initial report of four successful cases in 2002 by the senior author,⁵⁰ the outcome in 17 neonates treated in the time between 2004 and 2009 was excellent, with no intraoperative or postoperative complications.⁵¹ Nonetheless, others reported an unacceptably high incidence of anastomotic problems.⁵² These data suggest that this procedure should be performed in centers with ample experience in laparoscopic surgery in infants and that more data are necessary before recommending laparoscopic repair of duodenal atresia.

3.5. Malrotation

Since its first description by van der Zee et al.⁵³ several series on laparoscopic treatment of neonatal malrotation and midgut volvulus have been published.^{54–56} Contrary to the first description, some authors restricted the role of laparoscopy to cases without volvulus.^{54,57–59} However, several other reports document the feasibility of the laparoscopic approach in patients with volvulus and signs of intestinal ischemia were also present.^{55,60,61} Nonetheless, perforation, lack of tolerance of the CO₂ pneumoperitoneum as well as the difficult orientation can make a laparoscopic approach to midgut malrotation and volvulus impossible.⁶²

Although most reports cite an uncomplicated postoperative course, there are no prospective studies and no long-term follow-up. One recently published retrospective study comparing open versus laparoscopic therapy including a total of 156 patients observed a significantly increased readmission rate in the open group.⁶⁰ The laparoscopic approach was associated with a significantly shorter length of stay and time to full feeds, as well as a significantly lower rate of wound infections. Although the interpretation of these results is impaired by significant differences in patient characteristics and follow-up periods between both groups, the authors conclude that the laparoscopic approach to malrotation should be considered the treatment of choice. In another retrospective series of 37 children, including 22 aged <2 months, undergoing laparoscopic surgery for correction of malformation, Hagendoorn et al. describes a low rate of conversions or intraoperative complications.⁶³ Nonetheless, the rate of reoperation due to recurrence was significant. Based on these reports, it appears that laparoscopic treatment of malrotation in the neonate is feasible and may offer some benefits compared to the open approach. The lack of controlled and comparative data, however, makes it difficult to recommend this approach, unless performed by pediatric surgeons experienced in neonatal laparoscopic surgery.

3.6. Necrotizing enterocolitis

The timely diagnosis and correct grading of necrotizing enterocolitis is difficult, but crucial for the therapy. Several authors have enthusiastically described several cases of laparoscopic exploration

of premature infants with suspected necrotizing enterocolitis.^{64–68} If there were major perforations or necrotic bowel, the authors would then convert to an open procedure. In the presence of significant soiling, laparoscopy allowed guided placement of a drain. No complications were described in the reports and the authors recommend laparoscopy as a useful tool in the diagnosis and treatment of NEC. Nonetheless, the evidence supporting this procedure is low with only a few cases of laparoscopic exploration in NEC patients reported and no prospective or comparative data.

3.7. Inguinal hernia

Laparoscopic repair of inguinal hernia in children has become increasingly popular and numerous techniques have been described, but the benefit of the laparoscopic approach remains to be proven. In the general pediatric population, two prospective single-blinded randomized studies have been performed.^{69,70} Both observed significantly increased operation time in the minimally invasive group. One study found a significantly increased pain score and delayed recovery after laparoscopy,⁶⁹ whereas the other described a better cosmesis compared to the open group.⁷⁰ In two recently published retrospective series, Turial et al.^{71,72} described their personal experience with laparoscopic herniorrhaphy in premature infants ($n = 58$), or infants weighing <5 kg ($n = 147$). They reported an increased rate of secondary undescended testes in small premature infants, but a low rate of complications overall.

3.8. Anorectal malformation

Most cases of imperforate anus are repaired using traditional techniques, without intra-abdominal surgery. However, since its introduction in the treatment of high forms of imperforate anus by Georgeson et al. in 2000, laparoscopy has its role in the therapy of anorectal malformations.⁷³ Although a series of six patients who underwent primary single-procedure laparoscopic correction of high imperforate anus has been reported,⁷⁴ most surgeons prefer a delayed procedure after performing a divided colostomy and mucous fistula in the neonatal period.⁷⁵

4. Thoracoscopy in the neonate

Thoracotomy in infants is associated with significant long term sequelae such as shoulder movement impairment, rib fusions and scoliosis.⁷⁶ The incidence and severity of these deformities is significantly less in patients after thoracoscopic procedures.⁷⁷ This is a specific advantage of minimally invasive techniques in infants undergoing thoracic surgery.

4.1. Esophageal atresia and tracheoesophageal fistula

One of the classic indications for neonatal thoracic surgery is the correction of esophageal atresia and the associated tracheoesophageal fistula. Since the first thoracoscopic repair of an esophageal atresia in Berlin in 1999, the minimally invasive approach has been widely accepted as a valid option.⁷⁸ In a survey taken at the international scientific meeting of the British Association of Pediatric Surgeons in Edinburgh in 2007, 18% of the participating pediatric surgeons had performed a thoracoscopic repair of an esophageal atresia. About 50% of the surgeons stated that they intended to perform the repair of esophageal atresia thoracoscopically in the future.⁷⁹ After the feasibility of the approach was shown in small case series,^{80,81} a multinational and multi-institutional retrospective analysis of 104 patients revealed an outcome and complication rate comparable to previous reports of the open technique.⁸²

Similar results were reported by Lugo et al., who compared retrospectively the cases they performed thoracoscopically ($n = 8$) versus open ($n = 25$) in the period from 2000 to 2006.⁸³ Although the complication rate in the thoracoscopic group was lower, i.e. stricture rate of 14% versus 50% in the open group, the retrospective nature of their study makes a selection bias likely. Several technical modifications, such as special knotting techniques or an extrapleural approach, have been published, but there is a lack of prospective data to demonstrate the benefit of the thoracoscopic approach.

4.2. Congenital thoracic malformations

Routine prenatal ultrasound examinations have made the intrauterine detection of intrathoracic congenital lesions, such as congenital pulmonary airway malformation (CPAM), lung sequestration, bronchogenic cysts or lobar emphysema, possible. Symptomatic lesions require operation, but the majority of these lesions are asymptomatic at birth and there is an ongoing discussion about when and whether these lesions need surgery.^{84,85} There is no clear evidence as to the rate of complications developing in asymptomatic congenital lung malformations, but several reported cases of malignant transformation have been reported,^{86–88} as well as infectious complications which argue for early resection, even in asymptomatic cases.⁸⁴ In the last decade, many case series of successful thoracoscopic lobectomies and resection of malformations have demonstrated the feasibility of a minimally invasive approach.^{89,90} Nonetheless, many surgeons choose to operate electively after the neonatal period, e.g. at the age of six months.^{91,92} In recent years, however, thoracoscopic resection in the neonatal period has been proposed as therapy of choice.^{90,93,94} The advantage of an early operation, before potential infection or complication occurs, is the lack of adhesions, resulting in shorter operation times and less blood loss.⁹⁵ Although thoracoscopic treatment of congenital thoracic malformation is performed in many centers, there is little data comparing the thoracoscopic versus the open approach. In their retrospective comparison of open versus thoracoscopically performed resections of CPAM, Lu et al.⁹⁶ observed a significantly reduced postoperative hospital stay and a significantly lower complication rate in the thoracoscopically operated patients. However, in a case-matched study, comparing thoracoscopic versus open resection of congenital lung lesions, Diamond et al. observed no significant difference in terms of complication rate, hospital stay and pain medication.⁹⁷ Both authors describe the thoracoscopic approach as safe and feasible. So far, there has been no prospective study to clearly demonstrate the benefits of neonatal thoracoscopic therapy for congenital thoracic malformations.

4.3. Congenital diaphragmatic hernia

Although the first cases of laparoscopic treatment of congenital diaphragmatic hernias were performed two decades ago, this approach was long restricted to late-presenting hernias that were corrected in adults or adolescents.⁹⁸ Gradually, the age limit was pushed back, first to infants and then to truly neonatal correction of this potentially life-threatening defect.^{99–101} With growing experience, thoracoscopy was accepted as the preferred and technically easier approach compared to laparoscopy to perform congenital diaphragmatic hernia repair, as the insufflation of the CO₂ in the thoracic cavity supported the reduction of the abdominal organs.^{101–103} Several series support the feasibility of the repair of congenital diaphragmatic hernia by thoracoscopic surgery, but the selection criteria and long-term outcome compared to open surgery are still a matter of debate. Some studies comparing minimally invasive procedures with historic controls suggested

Table 1
Overview of laparoscopic and thoracoscopic procedures in the neonate

Type of procedure	Study design	Reported outcome
Laparoscopy		
Adhesiolysis	Several case reports and series	Feasible
Anorectal pull through	Several case reports	Feasible
Adrenalectomy	Several case reports	Feasible
Cholecystectomy	Case report	Feasible
Resection of choledochal cyst and hepaticojejunostomy	Several series	Feasible
Cholangiography	Several series	Feasible
Repair of diaphragmatic hernia	Several case reports	Feasible
Duodenoduodenostomy	Several series	Feasible
Fenestration/biopsy of liver masses	Several case reports	Feasible
Fundoplication and gastrostomy	Retrospective comparative study versus open	Similar rate of complications and time of operation
Closure of gastric perforation	Case report	Feasible
Gastropexy	Several case reports	Feasible
Resection of enteric duplications	Several case reports	Feasible
Jejunostomy	Several case reports	Feasible
Resection of lymphangioma	Several case reports	Feasible
Correction of malrotation	Retrospective comparative study versus open	Short term results superior
Resection of müllerian structures	Case report	Feasible
Visualization of necrotising enterocolitis	Several series	Feasible
Nephrectomy	Several case reports	Feasible
Treatment of ovarian cysts/torsion	Several series	Feasible
Pyloromyotomy	Several prospective randomized trials versus open surgery	Shorter hospital stay. Similar rate of complications
Resection of sacrococcygeal teratoma	Several series	Feasible
Correction of small bowel atresia	Several series	Feasible
Thoracoscopy		
Repair of diaphragmatic hernia	Several retrospective comparative studies versus open	Shorter hospital stay. Effect on morbidity and recurrence controversial
Diaphragmatic placcation	Several case reports	Feasible
Closure of patent ductus arteriosus	Several retrospective comparative studies versus open and coiling	Shortened operative time and hospital stay
Repair of esophageal atresia and tracheoesophageal fistula	Retrospective comparative studies versus open	Similar complication rates
Pericardial fenestration	Case report	Feasible
Lung biopsy	Several series	Feasible
Lung resections	Several retrospective comparative studies	Shorter hospital stay, similar or lower rate of complications
Resection of foregut duplications/bronchogenic cysts	Retrospective comparative studies versus open	Shortened hospital stay
Treatment of pneumatocele	Case reports	Feasible

similar recurrence and faster recovery.^{104,105} On the other hand, in a systematic review and meta-analysis of published cases, Landsdale et al. reported a higher recurrence rate and longer operation time, compared to open surgery.¹⁰⁶

5. Conclusion

Recently, the feasibility of minimally invasive surgery in the neonate has been demonstrated for a variety of indications. With modern equipment, it appears that there is no minimum age or weight criteria for laparoscopic or thoracoscopic interventions and there is increasing popularity for neonatal minimally invasive surgery in the pediatric surgical community. The focus of the academic work has shifted from the feasibility to the potential advantage or disadvantage of minimally invasive surgery in neonates and there is an increasing number of studies that include follow-up observations, comparisons with historic controls, matched control cases and prospective randomized trials. However, evidence for the benefit of minimally invasive surgery in the neonatal age group is still limited. Table 1 includes an overview of different indications for minimally invasive surgery in the neonate and the evidence supporting its use. Most reports are case series, and controlled prospective and randomized data remain rare. The

feasibility of minimally invasive surgical procedures does not necessarily translate into clinical benefit, as evidenced by the treatment of biliary atresia.¹⁰⁷ Thus, there is a demand for prospective multicenter studies and prospective databases in pediatric minimally invasive surgery, especially in the neonatal age group.¹⁰⁸ Nevertheless, several indications for minimally invasive surgery in neonates are already well established in specialized centers worldwide. The ongoing research to improve techniques and instruments aims at the use of less invasive surgery even in the very young.

Conflict of interest statement

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