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Video-Assisted Thoracoscopic or Conventional Thoracic Surgery in Infants and Children: Current Evidence

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Abstract

Introduction The pros and cons of video-assisted thoracoscopic versus conventional thoracic surgery in infants and children are still under debate. We assessed reported advantages and disadvantages of video-assisted thoracoscopy in pediatric surgical procedures, as well as the evidence level of the available data.

Materials and Methods A systematic literature search was performed to identify manuscripts comparing video-assisted thoracoscopic and the respective conventional thoracic approach in classic operative indications of pediatric surgery. Outcome parameters were analyzed and graded for level of evidence (according to the Oxford Centre of Evidence-Based Medicine).

Results A total of 48 comparative studies reporting on 12,709 patients, 11 meta-analyses, and one pilot randomized controlled trial including 20 patients were identified. More than 15 different types of advantages for video-assisted thoracoscopic surgery were described, mostly with a level of evidence 3b or 3a. Most frequently video-assisted thoracoscopic surgery was associated with shorter hospital stay, shorter postoperative ventilation, and shorter time to chest drain removal. Mortality rate and severe complications did not differ between thoracoscopic and conventional thoracic pediatric surgery, except for congenital diaphragmatic hernia repair with a lower mortality and higher recurrence rate after thoracoscopic repair. The most frequently reported disadvantage for video-assisted thoracoscopic surgery was longer operative time.

Conclusion The available data point toward improved recovery in pediatric video-assisted thoracoscopic surgery despite longer operative times. Further randomized controlled trials are needed to justify the widespread use of video assisted thoracoscopy in pediatric surgery.

Keywords
- thoracoscopy
- minimally invasive surgery
- children
- evidence

Introduction

The use of video-assisted thoracoscopic surgery (VATS) has exponentially gained popularity among pediatric surgeons over the last three decades.[1]

After initial diagnostic procedures reported in the mid 1970s,[2] the deployment of pediatric VATS was at the beginning slow, primarily because of the limitations of the instrumentation.[3] In the past 30 years, the development of suitably small, high-quality instruments, allowed minimally invasive

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surgery to be performed even in neonates.[3–5] This led to an increased acceptance of VATS among pediatric surgeons. Thoracoscopic approaches to over 20 types of pediatric and neonatal surgical diseases have been introduced at the beginning of the third millennium.[6]

Initially many enthusiastic reports and case series stated the feasibility and the safety of VATS for pediatric procedures. Proposed benefits of VATS included lower postoperative pain, shorter hospital stay, less wound infection rate, and less long-term musculoskeletal sequelae. However, high-evidence data demonstrating its benefit compared with conventional thoracic surgery (CTS) were lacking.[7,8]

The evidence level, that is, an evaluation of the scientific quality of studies and the grade of recommendation on which a physician should base his decision for or against a particular method, is commonly graded according to the classification published by the Oxford Centre of Evidence-Based Medicine (OCEBM).[9]

In a previous analysis including all studies comparing VATS to CTS in pediatric surgery up to 2012, we had focused on the scarcity of studies and the lack of randomized controlled trials (RCTs).[10] In the meanwhile, a growing number of pediatric surgical centers have implemented VATS.

We therefore expected an increasing number of studies concerning VATS in the present literature and thus aimed to analyze the current stand of the literature focusing on advantages and disadvantages of VATS in our present study.

Materials and Methods

Search and Selection Strategy

Comparative studies published in the English literature were identified by a Medline literature search using PubMed (*www.pubmed.com*). The applied search headings were the respective pediatric surgical diagnosis or procedure (i.e., “pulmonary sequestration” or “lung resection”) combined with the terms “minimally invasive surgery” or “thoracoscopy” and “infant” or “child” or “child, preschool” or “pediatric” and “comparative study” or “randomized controlled trial” or “meta-analysis.”

A total of 10 types of surgical procedures or diagnosis were searched by C.Z. and N.S. (►**Fig. 1**). Articles published until September 2019 were considered and selected according to our inclusion criteria.

Titles and abstracts were individually reviewed by R.K. and A.Z. and only those studies that specifically compared results and clinical outcome of VATS with the corresponding CTS in children were included for further analysis (►**Fig. 1**). This study was undertaken according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[11]

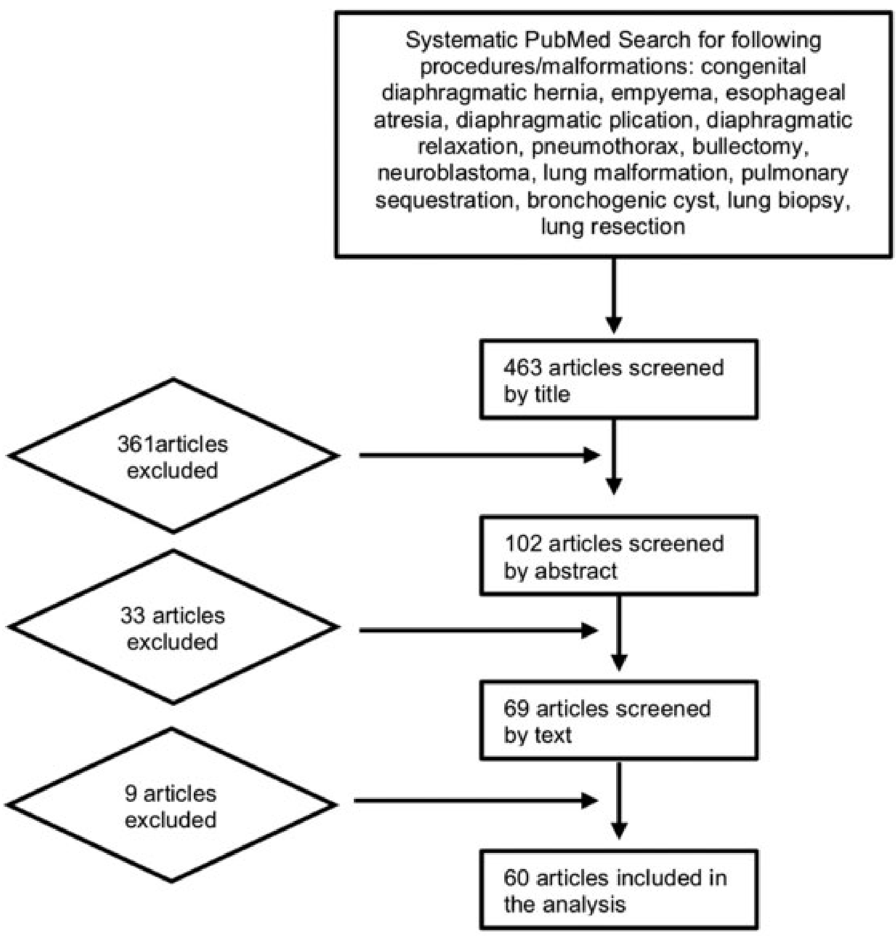

Fig. 1 Search and results of articles selection.

Eligibility

Studies were eligible for inclusion for further analysis if they studied pediatric patients, performed a direct comparison between VATS and CTS and included outcomes and/or operation data. Only full-text articles in English were included.

Studies were excluded from analysis if they were not published in English, reported on adult patients or robot-assisted surgery, did not provide sufficient demographic or outcome data, or were case reports or case series. Reference from conference proceedings were excluded when they were not published as journal article. Articles reporting on diagnostic procedures only and articles on empyema were also excluded, as the comparing procedures were thoracoscopic decortication and conservative treatment with chest tube drainage and fibrinolysis.

End Points

Primary end point was advantages and disadvantages of thoracoscopic procedures compared with the corresponding conventional thoracic operation. Secondary endpoint was their level of evidence in the literature. Advantages were defined as factors that facilitated operation, reduced the patient's morbidity, led to a faster recovery, or decreased complications. Disadvantages were defined as factors that led to higher complication rate or mortality, or prolonged the postoperative hospitalization. To evaluate the available evidence, the studies were classified in levels according to the OCEBM.[9] Ethical approval was not necessary as the study did not primarily involve human subjects.

None of the authors has competing financial interests to disclose.

Results

After systematic search (►Fig. 1), 60 manuscripts were included for further analysis. Studies available were 49 comparative studies reporting on a total of 12,709 patients and 11 meta-analyses (MAs). Of the comparative studies, one was an RCT (2%) reporting on 20 patients (0.02% of total number of patients)[12] and 48 were nonrandomized studies (NRSs); of these two were prospective NRSs (4%) reporting on 95 patients (0.8%)[7,13] and 46 were retrospective studies (94%) reporting on 12,594 patients (99.1%).

The RCT focused on two procedures: congenital diaphragmatic hernia and esophageal atresia.

The amount of comparative studies has been increasing in the last years (►Fig. 2). No comparative study was published from 1990 to 1999, while 13 NRSs were published during the following decade and 47 studies (35 NRSs, 1 RCT, and 11 MAs) since 2010.

Congenital Diaphragmatic Hernia Repair

Seventeen NRSs ($n = 8,124$ patients), five MAs, and one RCT ($n = 10$ patients) were identified (►Table 1). All NRSs had level 3b and all MAs level 3a of evidence.

Advantages of VATS

Length of hospital stay was reported in 11 NRSs comparing 3,499 patients.[14–24] Hospital stay was shorter in patients undergoing VATS diaphragmatic hernia repair in five NRSs (45.5%) including 3,287 patients (93.3%).[14,15,19–21]

Postoperative ventilation time was compared in 11 NRSs reporting on 562 patients.[14–20,23–26] Shorter postoperative ventilation after VATS repair was found in seven studies (63.6%) including 427 patients (45.1%).[14,15,19,20,23,25,26] Shorter

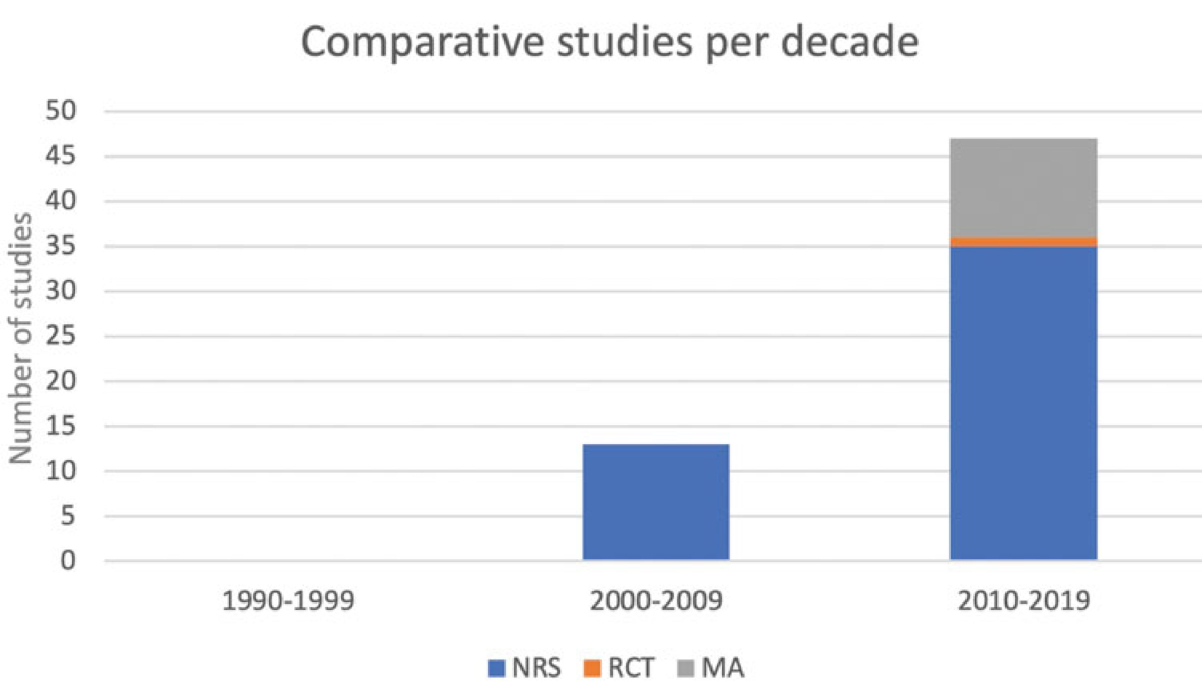

Fig. 2 Number of studies comparing video assisted thoracoscopic with conventional thoracic pediatric surgery during three decades. NRS, nonrandomized study; RCT, randomized controlled trial; MA, meta-analysis.

Table 1 Chronologic summary of studies comparing VATS to CTS for congenital diaphragmatic hernia repair

Congenital diaphragmatic hernia repair						
	Advantages of VATS				Disadvantages of VATS	
	Length of hospital stay	Time to chest drain removal	Ventilation time	other	Operative time	other
Nonrandomized studies						
Cho et al[16] (2009)	–	n/a	–		+	
Gourlay et al[23] (2009)	–	n/a	+	Time to feeding, narcotics use, costs, overall complications	+	
Lao et al[17] (2010)	–	n/a	–		+	
McHoney et al[29] (2010)	n/a	n/a	n/a		+	
Keijzer et al[30] (2010)	n/a	n/a	n/a		+	
Gander et al[15] (2011)	+	n/a	+		+	Recurrence
Fishman et al[22] (2011)	–	n/a	n/a		+	
Tsao et al[31] (2011)	n/a	n/a	n/a		–	Recurrence
Szavay et al[25] (2012)	n/a	n/a	+	Post-op pCO_2	+	
Nam et al[18] (2013)	–	n/a	–		–	
Tanaka et al[24] (2013)	–	n/a	–	Blood loss	–	
Bruns et al[74] (2016)	n/a	n/a	n/a		–	Recurrence
Costerus et al[26] (2016)	n/a	n/a	+		+	Recurrence
Tyson et al[20] (2017)	+	n/a	+		–	
Putnam et al[21] (2017)	+	n/a	n/a	Small bowel adhesion	–	Recurrence
Criss et al[14] (2018)	+	n/a	+	Time to feeding	–	
Qin et al[19] (2019)	+	n/a	+		–	
Randomized studies						
Bishay et al[12] (2013)	n/a	n/a	n/a	Analgesia	n/a	Hypercapnia and acidosis
Meta-analyses						
Lansdale et al[33] (2010)	n/a	n/a	n/a	–	+	Recurrence
Vijfhuize et al[28] (2012)	+	n/a	+	Mortality	+	Recurrence
Chan et al[27] (2014)	+	n/a	+	Mortality	+	Recurrence
Terui et al[34] (2015)	n/a	n/a	n/a	Mortality	n/a	Recurrence
Zhu et al[35] (2016)	n/a	n/a	n/a	Mortality, Complications	n/a	Recurrence

Abbreviations: CTS, conventional thoracic surgery; n/a, not available; VATS, video-assisted thoracoscopic surgery.
Note: Studies published in the last decade are shaded. All nonrandomized studies were retrospective (level of evidence 3b). All meta-analyses were level of evidence 3a.

hospital stay and shorter postoperative ventilation in patients undergoing VATS were confirmed in two MAs (evidence level 3a).[27,28]

Time to enteral feeding was described in six NRSs (evidence level 3b) including 251 patients.[14,16–18,23,24] Faster time to enteral feeding was reported in two NRSs (33.3%) including 89 patients.[14,23]

Lower postoperative need of narcotics, less severe complications,[23] lower blood loss,[24] and less small bowel adhesions[21] were other advantages for VATS (evidence level 3b).

Mortality rate was analyzed in five MAs. In four of them (80%), mortality was significantly lower in the VATS group (evidence level 3a). However, in the MAs mortality outcome was neither stratified according the type of diaphragmatic hernia nor the severity of the patient's conditions.

Disadvantages of VATS

Operative time was described in 12 NRSs including 593 patients[14–18,20,22,24–26,29] and it has reported to be longer in the VATS group in nine NRSs (75%) including 428 patients.[15–17,22,23,25,26,29,30] These findings were confirmed in all three MAs (level 3a of evidence).

Recurrence of diaphragmatic hernia was reported in 12 NRSs, including 7,993 patients.[14–16,18–22,25,26,30,31] The rate was significantly higher after thoracoscopic repair in five NRSs (41.7%) reporting on 7,611 patients. All MAs confirmed higher recurrence in the VATS group (level of evidence 3a).[28,32–35]

Intraoperative hypercapnia and acidosis during VATS was reported in one pilot RCT including 20 patients (level 2b). No differences were found regarding hospital stay and operative time between VATS and CTS.[12]

Esophageal Atresia Repair

Eight NRSs ($n = 307$ patients), four MAs, and one RCT ($n = 10$ patients) were identified (►Table 2). Except one study with level of evidence 2b[13] all other NRSs were 3b. All MAs had level of evidence 3a.

Advantages of VATS

Length of hospital stay was reported in five NRSs, comparing 200 patients.[13,36–39] In two of these studies (40%) including 100 patients (50%) shorter stay after VATS and faster time to enteral feeding were found.[37,39] The same findings were confirmed in two MAs (evidence level 3a).[40,41]

Postoperative ventilation time was found to be shorter in patients undergoing VATS repair of esophageal atresia in all studies reporting on this outcome. Four NRSs, including 169 patients, and two MAs (evidence level 3a).[13,36,37,39,41]

Shorter narcotics use, less anastomotic leakage, and stricture[39] and less early complications[42] were other reported advantages after VATS (evidence level 3b).

Disadvantages of VATS

Operative time was described in five NRSs, comparing 247 patients.[13,36,37,39,42,43] Longer operative time for VATS was reported in two studies (40%) including 101 patients.[13,43] This finding was confirmed in two MAs (evidence level 3a).[41,44]

No differences were found on long-term basis between VATS and CTS repair regarding distal esophageal motility and acid exposure in one NRS (evidence level 3b).[45] No differences in term of anastomotic leaks were found in all MAs (evidence level 3a).[40,41,44,46]

Table 2 Chronologic summary of studies comparing VATS to CTS for esophageal atresia repair

Esophageal atresia repair						
	Advantages of VATS				Disadvantages of VATS	
	Length of hospital stay	Time to chest drain removal	Ventilation time	other	Operative time	other
Nonrandomized studies ($n = 307$)						
Al Tokhais et al[42] (2008)	n/a	n/a	n/a	Overall early complications	–	
Lugo et al[39] (2008)	+	n/a	+	Leak, Stricture, Time to feeding, Narcotics use	–	
Kawahara et al[45] (2009)	n/a	n/a	n/a		n/a	
Szavay et al[43] (2011)	n/a	n/a	n/a		+	Intraoperative hypercapnia
Ma et al[13] (2012)[a]	–	n/a	+	Blood loss	+	
Yamoto et al[36] (2014)	–	–	+	Blood loss	–	
Koga et al[37] (2014)	+	–	+	Narcotics use, Blood loss, Respiratory complications, Time to feeding	–	Intraoperative hypercapnia and acidosis
Woo et al[38] (2015)	–	n/a	–		n/a	Vocal cord paresis
Randomized studies ($n = 10$)						
Bishay et al[12] (2013)	n/a	n/a	n/a		n/a	
Meta-analyses						
Borruto et al[46] (2012)	n/a	n/a	n/a		n/a	
Yang et al[40] (2016)	+	n/a	+	Time to feeding	n/a	
Wu et al[41] (2017)	+	n/a	+	Time to feeding	+	
Way et al[44] (2019)	n/a	n/a	n/a		+	

Abbreviations: CTS, conventional thoracic surgery; n/a, not available; VATS, video-assisted thoracoscopic surgery.
Note: Studies published in the last decade are shaded. All nonrandomized studies except one prospective (level of evidence 2b) were of retrospective nature (level of evidence 3b). All meta-analyses were level of evidence 3a.
[a]Prospective study.

The RCT (evidence level 2b), including 10 patients, found no differences in operative time and intraoperative variation of pH and pCO_2.[12]

Lung Resection

A total of 20 NRSs ($n = 3,718$ patients), 2 MAs and no RCT were identified (►Table 3). Apart from one study with level of evidence 2b,[7] all the others NRSs had level 3b. MAs had level of evidence 3a.

This group included lobectomy, atypical lung resection, and resection of lung malformations.

Advantages of VATS

Length of hospital stay was described in 17 NRSs, comparing a total of 3,726 patients.[47–63] Of these eight (41.2%) including 302 patients (8.1%) showed a shorter stay for thoracoscopic lung resections.[48–53,61] This finding was confirmed in both MAs (evidence level 3a).[64,65]

Time to chest drainage removal was described in 17 NRSs.[36,37,48–53,56–58,60,61,66–69] In 11 of them (64.7%), reporting on 388 patients (39.1%) was described faster removal after VATS resection.[48–53,61,66–69] In one out of two MAs was confirmed faster time to chest drainage removal after VATS compared with CTS (evidence level 3a).[65]

Shorter postoperative ventilation,[54,55] less regional anesthesia and narcotics use, shorter time in intensive care unit,[48,49] less blood loss,[53,54] and less overall complications[50,54] were further reported advantages of VATS (evidence level 3b).

Less musculoskeletal sequelae after VATS lung resection were described in one study (evidence level 2b).[7]

Table 3 Chronologic summary of studies comparing VATS to CTS for lung resection

Lung resection						
	Advantages of VATS				Disadvantages of VATS	
	Length of hospital stay	Time to chest drain removal	Ventilation time	other	Operative time	other
Nonrandomized studies ($n = 3,718$)						
Bonnard et al[47] (2004)	+	n/a	n/a	Narcotics use	–	
Tölg et al[51] (2005)	+	+	n/a		–	
Bratu et al[52] (2005)	+	+	n/a	Tracheal and esophageal injury	–	
Diamond et al[57] (2007)	–	–	–	Regional anesthesia	–	
Vu et al[50] (2008)	+	+	n/a	Complications	+	
Lawal et al[7] (2009)[a]	n/a	n/a	n/a	Chest asymmetry, Scoliosis, Cosmesis	n/a	
Rahman and Lakhoo[59] (2009)	–	n/a	n/a		+	
Reismann[75] 2012	n/a	n/a	n/a		n/a	
Fascetti-Leon et al[56] (2013)	–	–	–	–	n/a	Time to chest drain removal
Lau et al[48] (2013)	+	+	n/a	Time in ICU	–	
Kunisaki et al[60] (2014)	–	–	n/a		+	
Laje et al[58] (2015)	–	–	n/a		+	
Kulaylat et al[54] (2015)	–	n/a	+	Wound infection, Blood loss, Reoperation	–	
Wagenaar et al[61] (2015)	–	+	n/a		+	
Mattioli et al[62] (2016)	+	n/a	n/a		–	n/a
Polites et al[55] (2016)	–	n/a	+		n/a	
Sueyoshi et al[53] (2016)	+	+	n/a	Blood loss	–	
Wagenaar et al[63] (2016)	–	n/a	n/a		n/a	
Lau and Wong[49] 2018	+	+	n/a	Time in ICU	–	
Meta-analyses						
Nasr and Bass[65] (2012)	+	+	n/a		–	
Adams et al[64] (2017)	+	–	n/a	Complications	+	

Abbreviations: CTS, conventional thoracic surgery; ICU, intensive care unit; n/a, not available; VATS, video-assisted thoracoscopic surgery.
Note: Studies published in the last decade are shaded. All nonrandomized studies except one prospective (level of evidence 2b) were of retrospective nature (level of evidence 3b). All meta-analyses were level of evidence 3a.
[a]Prospective study.

Disadvantages of VATS

Operative time was reported in 14 NRSs, reporting on 1,016 patients.[47–54,57–62] In five of them (35.7%), including 455 patients (44.8%) was described longer operative time for thoracoscopic lung resection.[50,58–61] This finding could be confirmed in one MA,[64] while in another one no significant difference was found in operative time between thoracoscopic and conventional lung resection.[65]

Resection of Thoracic Neuroblastoma

Two NRSs ($n = 54$ patients), no MA, and no RCT were identified (►Table 4). Both NRSs had level of evidence 3b.

Advantages of VATS

Shorter hospital stay and faster time to chest drainage removal were the reported advantages after VATS in both studies.[66,67] Both studies analyzed blood loss, but just in one study, blood loss was found inferior during VATS,[66] while in the other one no statistical differences were found between VATS and CTS.[67]

Disadvantages of VATS

No disadvantages were reported.

No differences were found regarding operative time, intraoperative complications, tumor recurrence, and disease-free survival rate.[66,67]

Plication of Diaphragm

One NRS ($n = 35$ patients), no MA and no RCT were identified (►Table 4). The level of evidence was 3b. In this NRS, 18 infants undergoing posterolateral thoracotomy were compared with 17 patients undergoing thoracoscopic diaphragmatic plication.

Advantages of VATS

Length of hospital stay, operative time, narcotics use, and length of intensive care unit stay were described as shorter after VATS compared with CTS diaphragmatic plication.[69]

Disadvantages of VATS

No disadvantages were reported.

No differences were found in the postoperative complications.

Treatment of Spontaneous Pneumothorax

One NRS ($n = 31$ patients), no MA and no RCT were identified (►Table 4). The level of evidence was 3b.

We considered only studies that compared thoracoscopic to conventional bullectomy with or without pleurodesis. Studies comparing VATS with primary chest drainage insertion were excluded.

In this NRS, 13 patients undergoing limited axillary thoracotomy were compared with 13 patients undergoing thoracoscopic bullectomy.[68] Regardless of the technique (VATS or CTS) bullectomies were performed with automatic stapling devices.

Advantages of VATS

Length of hospital stay, time to removal chest drainage and length of narcotics use were described shorter after VATS compared with the conventional bullectomy.

Disadvantages of VATS

No disadvantages were reported.

No difference regarding recurrence was found between the two groups.

Overall Advantages and Disadvantages of VATS

At least one advantage of VATS compared with CTS was described in 31 out of 49 NRSs (63.3%). The most described advantages (evidence level 3b) favoring VATS were shorter hospital stay (51.4% of the studies), earlier removal of chest drainage (64.7%), shorter postoperative ventilation (70%), and shorter duration of chest drain (78.6%). Shorter hospital stay was confirmed in all MAs (evidence level 3a) that considered this parameter for congenital diaphragmatic hernia repair, esophageal atresia repair, and lung resection.

Table 4 Chronologic summary of studies comparing VATS to CTS for treatment of spontaneous pneumothorax, resection of thoracic neuroblastoma and plication of diaphragm

Various nonrandomized studies						
	Advantages of VATS				Disadvantages of VATS	
	Length of hospital stay	Time to chest drain removal	Ventilation time	other	Operative time	other
Treatment of spontaneous pneumothorax ($n = 31$)						
Butterworth et al[68] (2007)	+	+	n/a	Recurrence	–	n/a
Resection of thoracic neuroblastoma ($n = 54$)						
Petty et al[67] (2006)	+	+	n/a		–	n/a
Malek et al[66] (2010)	+	+	n/a	Blood loss	–	n/a
Plication of diaphragm ($n = 35$)						
Kozlov and Novozhilov[69] (2015)	+	+	n/a	Operative time, Time in ICU	–	–

Abbreviations: CTS, conventional thoracic surgery; ICU, intensive care unit; n/a, not available; VATS, video-assisted thoracoscopic surgery.
Note: Studies published in the last decade are shaded. All nonrandomized studies were retrospective (level of evidence 3b). No meta-analyses were available.

Except for congenital hernia repair, no differences in term of mortality or severe complications were found.

At least one disadvantage of VATS compared with CTS was described in 23 out of 49 studies (46.9%). The most frequent disadvantage (evidence level 3b) of VATS was longer operative time (43.2% of the studies). Longer operative time in patients undergoing VATS procedure was found in all MAs (evidence level 3a) for congenital diaphragmatic hernia repair, esophageal atresia repair, and lung resection. The main advantages and disadvantages are summarized in ►Table 5.

Discussion

Despite the numerous innovations in surgical equipment and a constant evolution of surgical techniques,[4] the use of VATS in children and infants is still based on anecdotal evidence for many thoracic surgical indications.[10]

In a recent review of MAs, the benefits of minimally invasive surgery have clearly been shown for several types of laparoscopic procedures in children.[70] However, corresponding analyses for thoracoscopic procedures were lacking. The few MAs concerning VATS were based on a limited

Table 5 Main advantages and disadvantages of VATS

Advantages of VATS			Disadvantages of VATS		
Advantage	**Number of studies**	**Number of patients**	**Disadvantage**	**Number of studies**	**Number of patients**
Congenital diaphragmatic hernia repair					
Postoperative ventilation	7 NRSs (63.6%)	253 (45%)	Operative time	9 NRSs (75%)	428 (72.1%)
	4 MAs	–		3 MAs	–
Length of hospital stay	5 NRSs (45.5%)	3,287 (93.9%)	Recurrence	5 NRSs (41.6%)	7,611 (95.2%)
	2 MAs	–		5 MAs	–
Mortality	4 MAs	–	Hypercapnia and acidosis intraoperative	1 RCT (100%)	10 (100%)
Esophageal atresia repair					
Postoperative ventilation	4 NRSs (100%)	169 (100%)	Operative time	2 NRSs (40%)	66 (26.7%)
	2 MAs	–			
Length of hospital stay	2 NRSs (40%)	98 (49%)		2 MAs	–
	2 MAs	–			
Time to feeding	2 MAs	–			
Lung resection					
Chest drainage	7 NRSs (72.7%)	268 (41.8%)	Operative time	5 NRSs (35.7%)	455 (44.8%)
	1 MA	–			
Length of hospital stay	8 NRSs (41.2%)	302 (8.1%)		1 MA (50%)	–
	2 MAs	–			
Resection of thoracic neuroblastoma					
Length of hospital stay	2 NRSs (100%)	54 (100%)	–		
Chest drainage duration					
Blood loss	1 NRS (50%)	37 (68.5%)			
Plication of diaphragm					
Length of hospital stay	1 NRS (100%)	35 (100%)	–		
Chest drainage duration					
Ventilation postoperative					
Operative time					
Treatment of spontaneous pneumothorax					
Length of hospital stay	1 NRS (100%)	31 (100%)	–		
Chest drainage duration					
Pain					

Abbreviations: MA, meta-analysis; NRS, nonrandomized studies; VATS, video-assisted thoracoscopic surgery.
Note: Number of studies and patients and their percentages are referred to studies that analyzed the specific outcome.

number of nonrandomized reports and covered only three types of thoracic procedures. Nonetheless, since our last review in 2013,[10] numerous studies comparing VATS and CTS in children and infants have been released, including 31 NRSs, 8 MAs, and 1 pilot RCT. It is promising that after more than 30 years, an increasing number of studies comparing VATS versus CTS has been published. In the last decade the number of studies almost triplicated, and many studies that had not yet been included in MAs were now released. To evaluate the development of reporting concerning advantages and disadvantages of VATS in pediatric surgery, in the present study, we analyzed not only the recent publications but rather the entire literature comparing pediatric VATS to CTS.

VATS was associated with more than 15 different advantages and in more than half of the studies no disadvantage was mentioned. At least one advantage of VATS was described in 63.3% of the studies. The most described advantages favoring VATS were shorter hospital stay, earlier removal of chest drainage, shorter postoperative ventilation, and shorter duration of chest drain.

At least one disadvantage of VATS compared with CTS was reported in about half of the studies. The most reported disadvantage of VATS was longer operative time. Nonetheless, mortality and major complications rate did not differ between VATS and CTS. The exception was thoracoscopic congenital diaphragmatic hernia repair which was associated with a lower mortality but higher recurrence rate.

However, the estimation and the interpretation of outcomes were often subjective and sometimes appeared to be biased. First of all, the vast majority of studies were of retrospective nature (level of evidence 3b) or MAs of retrospective studies (level 3a), achieving a low/moderate level of evidence. The only RCT identified was a pilot study and included a vanishing number of patients, representing approximately 0.02% of all the studied patients (level of evidence 2b).

Additionally, the lack of randomization intrinsically leads to an intentional selection of the patients undergoing one procedure rather than other. For instance, with regard to congenital diaphragmatic hernia, more stable patients were more likely to undergo VATS repair. This selection bias in congenital diaphragmatic hernia becomes particularly evident when considering that the significantly lower mortality rates described after VATS repair were not stratified according to the severity of the defect or the hemodynamic status of the patients.

Moreover, the lack of standardized perioperative protocols could have influenced the outcomes. For example, some protocols advocate chest drain removal the day after elective thoracoscopic but not after conventional surgery. Early removal of chest drain not only may appear as a direct advantage of VATS but also influences the length of hospital stay.[71] A similar effect can be observed for enteral feeding after thoracoscopic esophageal atresia repair.

Finally, an "underreporting" bias has to be considered. Some centers, with unfavorable outcomes may not have been motivated to publish their comparative series, leading to an underrepresentation of disadvantages of VATS and to a misinterpretation of the VATS reality in pediatric surgery.

Despite the lack of high level of evidence and potential bias, the consistently described advantages of thoracoscopic approach in pediatric surgery and the huge number of patients demonstrate the potential benefit of this minimal invasive approach. Nonetheless our study also identified some frequently reported disadvantages. VATS was often associated with longer operative time regardless of the type of surgery.

While the disadvantages might be diminished with increased experience,[72] the higher recurrence rate in congenital diaphragmatic hernia, given the assumption that the majority of infants chosen for thoracoscopic repair were at low risk and may be considered unacceptable. Nonetheless, a study from the Congenital Diaphragmatic Hernia Study Group has shown that early recurrence rates for the VATS approach over the last years of the study period (2010–2014) have been similar to the conventional approach, while the initial (2007–2010) VATS recurrence rates were approximately three times higher.[73]

This suggests that with a high level of expertise the disadvantages of VATS could be minimized. However, numerous centers struggle with insufficient case volumes to adequately train their staff. Therefore, steps to improve training, such as centralization, may be encouraged to optimize the quality of care.

Conclusion

Several advantages of VATS were reported in 60 comparative studies analyzing data from 12,709 pediatric patients. However, the level of evidence was low and the selection bias possibly high. Therefore, RCTs are mandatory to achieve higher level of evidence and elucidate some critical points of video-assisted thoracoscopy in pediatric surgery.

Conflict of Interest
None declared.

References

1 Ure B. Enthusiasm, evidence and ethics: the triple E of minimally invasive pediatric surgery. J Pediatr Surg 2013;48(01):27–33
2 Rodgers BM, Moazam F, Talbert JL. Thoracoscopy in children. Ann Surg 1979;189(02):176–180
3 Lacher M, Kuebler JF, Dingemann J, Ure BM. Minimal invasive surgery in the newborn: current status and evidence. Semin Pediatr Surg 2014;23(05):249–256
4 Kuebler JF, Ure BM. Minimally invasive surgery in the neonate. Semin Fetal Neonatal Med 2011;16(03):151–156
5 Macchini F, Zanini A, Morandi A, Ichino M, Leva E. Thoracoscopic surgery for congenital lung malformation using miniaturized 3-mm vessel sealing and 5-mm stapling devices: single-center experience. J Laparoendosc Adv Surg Tech A 2020;30(04):444–447
6 Ure BM, Schmidt AI, Jesch NK. Thoracoscopic surgery in infants and children. Eur J Pediatr Surg 2005;15(05):314–318
7 Lawal TA, Gosemann J-H, Kuebler JF, Glüer S, Ure BM. Thoracoscopy versus thoracotomy improves midterm musculoskeletal status and cosmesis in infants and children. Ann Thorac Surg 2009;87(01):224–228

8 Blinman T, Ponsky T. Pediatric minimally invasive surgery: laparoscopy and thoracoscopy in infants and children. Pediatrics 2012;130(03):539–549
9 OCEBM Levels of Evidence. Available at: http://www.cebm.net/index.aspx?o=5653. Accessed September 1, 2020
10 Dingemann C, Ure B, Dingemann J. Thoracoscopic procedures in pediatric surgery: what is the evidence? Eur J Pediatr Surg 2014;24(01):14–19
11 Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med 2009;6(07):e1000100
12 Bishay M, Giacomello L, Retrosi G, et al. Hypercapnia and acidosis during open and thoracoscopic repair of congenital diaphragmatic hernia and esophageal atresia: results of a pilot randomized controlled trial. Ann Surg 2013;258(06):895–900
13 Ma L, Liu Y-Z, Ma Y-Q, Zhang S-S, Pan N-L. Comparison of neonatal tolerance to thoracoscopic and open repair of esophageal atresia with tracheoesophageal fistula. Chin Med J (Engl) 2012;125(19):3492–3495
14 Criss CN, Coughlin MA, Matusko N, Gadepalli SK. Outcomes for thoracoscopic versus open repair of small to moderate congenital diaphragmatic hernias. J Pediatr Surg 2018;53(04):635–639
15 Gander JW, Fisher JC, Gross ER, et al. Early recurrence of congenital diaphragmatic hernia is higher after thoracoscopic than open repair: a single institutional study. J Pediatr Surg 2011;46(07):1303–1308
16 Cho SD, Krishnaswami S, Mckee JC, Zallen G, Silen ML, Bliss DW. Analysis of 29 consecutive thoracoscopic repairs of congenital diaphragmatic hernia in neonates compared to historical controls. J Pediatr Surg 2009;44(01):80–86
17 Lao OB, Crouthamel MR, Goldin AB, Sawin RS, Waldhausen JHT, Kim SS. Thoracoscopic repair of congenital diaphragmatic hernia in infancy. J Laparoendosc Adv Surg Tech A 2010;20(03):271–276
18 Nam SH, Cho MJ, Kim DY, Kim SC. Shifting from laparotomy to thoracoscopic repair of congenital diaphragmatic hernia in neonates: early experience. World J Surg 2013;37(11):2711–2716
19 Qin J, Ren Y, Ma D. A comparative study of thoracoscopic and open surgery of congenital diaphragmatic hernia in neonates. J Cardiothorac Surg 2019;14(01):118
20 Tyson AF, Sola R Jr., Arnold MR, Cosper GH, Schulman AM. Thoracoscopic versus open congenital diaphragmatic hernia repair: single tertiary center review. J Laparoendosc Adv Surg Tech A 2017;27(11):1209–1216
21 Putnam LR, Tsao K, Lally KPCongenital Diaphragmatic Hernia Study Group and the Pediatric Surgery Research Collaborative, et al; Minimally invasive vs open congenital diaphragmatic hernia repair: is there a superior approach? J Am Coll Surg 2017;224(04):416–422
22 Fishman JR, Blackburn SC, Jones NJ, et al. Does thoracoscopic congenital diaphragmatic hernia repair cause a significant intraoperative acidosis when compared to an open abdominal approach? J Pediatr Surg 2011;46(03):458–461
23 Gourlay DM, Cassidy LD, Sato TT, Lal DR, Arca MJ. Beyond feasibility: a comparison of newborns undergoing thoracoscopic and open repair of congenital diaphragmatic hernias. J Pediatr Surg 2009;44(09):1702–1707
24 Tanaka T, Okazaki T, Fukatsu Y, et al. Surgical intervention for congenital diaphragmatic hernia: open versus thoracoscopic surgery. Pediatr Surg Int 2013;29(11):1183–1186
25 Szavay PO, Obermayr F, Maas C, Luenig H, Blumenstock G, Fuchs J. Perioperative outcome of patients with congenital diaphragmatic hernia undergoing open versus minimally invasive surgery. J Laparoendosc Adv Surg Tech A 2012;22(03):285–289
26 Costerus S, Zahn K, van de Ven K, Vlot J, Wessel L, Wijnen R. Thoracoscopic versus open repair of CDH in cardiovascular stable neonates. Surg Endosc 2016;30(07):2818–2824
27 Chan E, Wayne C, Nasr A. Minimally invasive versus open repair of Bochdalek hernia: a meta-analysis. J Pediatr Surg 2014;49(05):694–699
28 Vijfhuize S, Deden AC, Costerus SA, Sloots CE, Wijnen RM. Minimal access surgery for repair of congenital diaphragmatic hernia: is it advantageous?–An open review Eur J Pediatr Surg 2012;22(05):364–373
29 McHoney M, Giacomello L, Nah SA, et al. Thoracoscopic repair of congenital diaphragmatic hernia: intraoperative ventilation and recurrence. J Pediatr Surg 2010;45(02):355–359
30 Keijzer R, van de Ven C, Vlot J, et al. Thoracoscopic repair in congenital diaphragmatic hernia: patching is safe and reduces the recurrence rate. J Pediatr Surg 2010;45(05):953–957
31 Tsao K, Lally PA, Lally KPCongenital Diaphragmatic Hernia Study Group. Minimally invasive repair of congenital diaphragmatic hernia. J Pediatr Surg 2011;46(06):1158–1164
32 Chan YY, Durbin-Johnson B, Sturm RM, Kurzrock EA. Outcomes after pediatric open, laparoscopic, and robotic pyeloplasty at academic institutions. J Pediatr Urol 2017;13(01):49.e1–49.e6
33 Lansdale N, Alam S, Losty PD, Jesudason EC. Neonatal endosurgical congenital diaphragmatic hernia repair: a systematic review and meta-analysis. Ann Surg 2010;252(01):20–26
34 Terui K, Nagata K, Ito M, et al. Surgical approaches for neonatal congenital diaphragmatic hernia: a systematic review and meta-analysis. Pediatr Surg Int 2015;31(10):891–897
35 Zhu Y, Wu Y, Pu Q, Ma L, Liao H, Liu L. Minimally invasive surgery for congenital diaphragmatic hernia: a meta-analysis. Hernia 2016;20(02):297–302
36 Yamoto M, Urusihara N, Fukumoto K, et al. Thoracoscopic versus open repair of esophageal atresia with tracheoesophageal fistula at a single institution. Pediatr Surg Int 2014;30(09):883–887
37 Koga H, Yamoto M, Okazaki T, et al. Factors affecting postoperative respiratory tract function in type-C esophageal atresia. Thoracoscopic versus open repair. Pediatr Surg Int 2014;30(12):1273–1277
38 Woo S, Lau S, Yoo E, Shaul D, Sydorak R. Thoracoscopic versus open repair of tracheoesophageal fistulas and rates of vocal cord paresis. J Pediatr Surg 2015;50(12):2016–2018
39 Lugo B, Malhotra A, Guner Y, Nguyen T, Ford H, Nguyen NX. Thoracoscopic versus open repair of tracheoesophageal fistula and esophageal atresia. J Laparoendosc Adv Surg Tech A 2008;18(05):753–756
40 Yang Y-F, Dong R, Zheng C, et al. Outcomes of thoracoscopy versus thoracotomy for esophageal atresia with tracheoesophageal fistula repair: A PRISMA-compliant systematic review and meta-analysis. Medicine (Baltimore) 2016;95(30):e4428
41 Wu Y, Kuang H, Lv T, Wu C. Comparison of clinical outcomes between open and thoracoscopic repair for esophageal atresia with tracheoesophageal fistula: a systematic review and meta-analysis. Pediatr Surg Int 2017;33(11):1147–1157
42 Al Tokhais T, Zamakhshary M, Aldekhayel S, et al. Thoracoscopic repair of tracheoesophageal fistulas: a case-control matched study. J Pediatr Surg 2008;43(05):805–809
43 Szavay PO, Zundel S, Blumenstock G, et al. Perioperative outcome of patients with esophageal atresia and tracheo-esophageal fistula undergoing open versus thoracoscopic surgery. J Laparoendosc Adv Surg Tech A 2011;21(05):439–443
44 Way C, Wayne C, Grandpierre V, Harrison BJ, Travis N, Nasr A. Thoracoscopy vs. thoracotomy for the repair of esophageal atresia and tracheoesophageal fistula: a systematic review and meta-analysis. Pediatr Surg Int 2019;35(11):1167–1184
45 Kawahara H, Okuyama H, Mitani Y, et al. Influence of thoracoscopic esophageal atresia repair on esophageal motor function and gastroesophageal reflux. J Pediatr Surg 2009;44(12):2282–2286
46 Borruto FA, Impellizzeri P, Montalto AS, et al. Thoracoscopy versus thoracotomy for esophageal atresia and tracheoesophageal fistula

repair: review of the literature and meta-analysis. Eur J Pediatr Surg 2012;22(06):415–419
47 Bonnard A, Malbezin S, Ferkdadji L, Luton D, Aigrain Y, de Lagauise P. Pulmonary sequestration children: is the thoracoscopic approach a good option? Surg Endosc 2004;18(09):1364–1367
48 Lau CT, Leung L, Chan IHY, et al. Thoracoscopic resection of congenital cystic lung lesions is associated with better postoperative outcomes. Pediatr Surg Int 2013;29(04):341–345
49 Lau C-T, Wong KKY. Long-term pulmonary function after lobectomy for congenital pulmonary airway malformation: is thoracoscopic approach really better than open? J Pediatr Surg 2018;53(12):2383–2385
50 Vu LT, Farmer DL, Nobuhara KK, Miniati D, Lee H. Thoracoscopic versus open resection for congenital cystic adenomatoid malformations of the lung. J Pediatr Surg 2008;43(01):35–39
51 Tölg C, Abelin K, Laudenbach V, et al. Open vs thorascopic surgical management of bronchogenic cysts. Surg Endosc 2005;19(01):77–80
52 Bratu I, Laberge J-M, Flageole H, Bouchard S. Foregut duplications: is there an advantage to thoracoscopic resection? J Pediatr Surg 2005;40(01):138–141
53 Sueyoshi R, Koga H, Suzuki K, et al. Surgical intervention for congenital pulmonary airway malformation (CPAM) patients with preoperative pneumonia and abscess formation: “open versus thoracoscopic lobectomy”. Pediatr Surg Int 2016;32(04):347–351
54 Kulaylat AN, Engbrecht BW, Hollenbeak CS, Safford SD, Cilley RE, Dillon PW. Comparing 30-day outcomes between thoracoscopic and open approaches for resection of pediatric congenital lung malformations: Evidence from NSQIP. J Pediatr Surg 2015;50(10):1716–1721
55 Polites SF, Habermann EB, Zarroug AE, Thomsen KM, Potter DD. Thoracoscopic Vs open resection of congenital cystic lung disease- utilization and outcomes in 1120 children in the United States. J Pediatr Surg 2016;51(07):1101–1105
56 Fascetti-Leon F, Gobbi D, Pavia SV, et al. Sparing-lung surgery for the treatment of congenital lung malformations. J Pediatr Surg 2013;48(07):1476–1480
57 Diamond IR, Herrera P, Langer JC, Kim PCW. Thoracoscopic versus open resection of congenital lung lesions: a case-matched study. J Pediatr Surg 2007;42(06):1057–1061
58 Laje P, Pearson EG, Simpao AF, et al. The first 100 infant thoracoscopic lobectomies: Observations through the learning curve and comparison to open lobectomy. J Pediatr Surg 2015;50(11):1811–1816
59 Rahman N, Lakhoo K. Comparison between open and thoracoscopic resection of congenital lung lesions. J Pediatr Surg 2009;44(02):333–336
60 Kunisaki SM, Powelson IA, Haydar B, et al. Thoracoscopic vs open lobectomy in infants and young children with congenital lung malformations. J Am Coll Surg 2014;218(02):261–270
61 Wagenaar AE, Tashiro J, Hirzel A, et al. Surgical management of bronchopulmonary malformations. J Surg Res 2015;198(02):406–412
62 Mattioli G, Pio L, Disma NM, et al. Congenital lung malformations: shifting from open to thoracoscopic surgery. Pediatr Neonatol 2016;57(06):463–466
63 Wagenaar AE, Tashiro J, Satahoo SS, et al. Resection of pediatric lung malformations: national trends in resource utilization & outcomes. J Pediatr Surg 2016;51(09):1414–1420
64 Adams S, Jobson M, Sangnawakij P, et al. Does thoracoscopy have advantages over open surgery for asymptomatic congenital lung malformations? An analysis of 1626 resections. J Pediatr Surg 2017;52(02):247–251
65 Nasr A, Bass J. Thoracoscopic vs open resection of congenital lung lesions: a meta-analysis. J Pediatr Surg 2012;47(05):857–861
66 Malek MM, Mollen KP, Kane TD, Shah SR, Irwin C. Thoracic neuroblastoma: a retrospective review of our institutional experience with comparison of the thoracoscopic and open approaches to resection. J Pediatr Surg 2010;45(08):1622–1626
67 Petty JK, Bensard DD, Partrick DA, Hendrickson RJ, Albano EA, Karrer FM. Resection of neurogenic tumors in children: is thoracoscopy superior to thoracotomy? J Am Coll Surg 2006;203(05):699–703
68 Butterworth SA, Blair GK, LeBlanc JG, Skarsgard ED. An open and shut case for early VATS treatment of primary spontaneous pneumothorax in children. Can J Surg 2007;50(03):171–174
69 Kozlov Y, Novozhilov V. Thoracoscopic plication of the diaphragm in infants in the first 3 months of life. J Laparoendosc Adv Surg Tech A 2015;25(04):342–347
70 Schukfeh N, Kuebler JF, Dingemann J, Ure BM. Thirty years of minimally invasive surgery in children: analysis of meta-analyses. Eur J Pediatr Surg 2019. Doi: 10.1055/s-0039-1687901
71 Sienel W, Mueller J, Eggeling S, Thetter O, Passlick B. [Early chest tube removal after video-assisted thoracoscopic surgery. Results of a prospective randomized study] (in German). Chirurg 2005;76(12):1155–1160
72 Uecker M, Kuebler JF, Ure BM, Schukfeh N. Minimally invasive pediatric surgery: the learning curve. Eur J Pediatr Surg 2020;30(02):172–180
73 Putnam LR, Gupta V, Tsao K; Congenital Diaphragmatic Hernia Study Group, et al; Factors associated with early recurrence after congenital diaphragmatic hernia repair. J Pediatr Surg 2017;52(06):928–932
74 Bruns NE, Glenn IC, McNinch NL, Arps K, Ponsky TA, Schlager A. Approach to recurrent congenital diaphragmatic hernia: results of an international survey. J Laparoendosc Adv Surg Tech A 2016;26(11):925–929
75 Reismann M, Gossner J, Glueer S, Schwerk N, Ure BM, Metzelder ML. Thoracoscopic resection of congenital pulmonary malformations in infants: is the feasibility related to the size of the lesion? World J Pediatr 2012;8(03):272–274