Review Article

Thoracoscopy in pediatrics: Surgical perspectives

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Abstract:

Thoracoscopic surgery and other minimally invasive approaches in children achieved marked advancement and expanded to include several disciplines in the last decade. The new armamentarium of the minimally invasive surgery including the smaller instruments and better magnification led to the application of this technology in the small infants and neonates. Currently, thoracoscopy is considered the preferred surgical approach for various conditions in neonates and infants over the standard thoracotomy, and thoracoscopic training is included in the surgical training curriculum for the residents in many institutes worldwide. Children are different from adults, and technique modifications are required when using thoracoscopy in children. Thoracoscopy showed satisfactory results in several operations including pulmonary resections, mediastinal tumors biopsies or resections, repair of the diaphragmatic hernias, decortication, and tracheoesophageal fistula. This review aims to address the unique aspects of thoracoscopic surgery in children, identify its potential technical and anatomical challenges, and the proposed solutions. A literature search for latest and relevant publications was done using the keywords (thoracoscopy; pediatric; lung biopsy; decortication; lobectomy; mediastinum; esophagus; and diaphragmatic hernia).

Keywords:

Decortication, diaphragmatic hernia, esophagus, lobectomy, lung biopsy, mediastinum, pediatric, thoracoscopy

Minimally invasive surgical (MIS) techniques have been increasingly applied in pediatric surgery, and thoracoscopy is currently considered the standard approach for several procedures[1-3] MIS is preferred because it is associated with reduced tissue trauma, decreased pain, reduced hospital stay, and equal or even better clinical outcomes when compared to the standard surgical approaches.[4,5] Thoracoscopy is considered now the preferred approach for several surgical interventions including the lung and mediastinal biopsies, as well as decortication for empyema. Currently, several pediatric centers worldwide have adapted many advanced thoracoscopic procedures, including lobectomies, esophageal surgery, and diaphragmatic hernia repair.[6]

Jaureguizar *et al*.[7] reported significant musculoskeletal deformities postoperatively in 35% of patients who had a tracheoesophageal fistula repair through a thoracotomy, and scoliosis developed in 30% of the neonates. Better long-term muscular skeletal morbidity was reported after thoracoscopy, in addition to the superior cosmetic results.[5] Moreover, thoracoscopy was associated with better postoperative pulmonary mechanics, and consequently lower hospital stay and wound-related complications.[5] Shorter hospital stay following thoracoscopy is one of its main advantages, and thoracoscopic lung and mediastinal biopsies and patent ductus arteriosus (PDA) repair can be discharged within 24 h of the procedure.[8] In addition to the direct impact on the patients

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and procedure outcomes, thoracoscopy provides the surgeons with higher magnification leading to better visibility of the vital structure thus avoiding their injury.

Thoracoscopy is not without risks and compared to the open approaches; thoracoscopic procedures are technically more demanding due to the smaller working field, difficult hemostasis, lack of tactile feedback, and two-dimensional vision. These factors have a direct impact on the learning curve for thoracoscopic surgery and may influence the outcomes. The question is whether the benefits of thoracoscopy outweigh its risk and steep learning curve.

The aim of this review is to address the unique aspects of thoracoscopic surgery in the pediatric population, identify its potential challenges and the proposed solutions. A literature search of several databases such as "PubMed, Ovid, and Science Direct" was performed. The keywords used were "thoracoscopy and pediatrics and lung biopsy or empyema or lobectomy or esophageal surgery or mediastinal surgery or patent ductus arteriosus ligation." Relevant and latest publications were identified and discussed.

Historical Background

Thoracoscopy in pediatric patients was first described in 1971 by Klimkovich and coworkers who performed diagnostic procedures for mediastinal and lung lesions,[9,10] Rothenberg *et al*. reported the first thoracoscopic lung lobectomy in 1994–1995,[11,12] and the first thoracoscopic pure esophageal atresia repair was performed in Berlin in 1999.[13]

Anatomical and Physiological Issues

Children are different from adults not only anatomically and physiologically but also emotionally. These factors may require modifications to the techniques used in adults to avoid complications.[14] Most of the complications can be managed thoracoscopically depending on its nature and the surgeons' experience; however, the conversion to open thoracotomy is still required in up to 17% of cases.[15] Complications can be broadly classified into complications related to the approach and procedure-specific complications. Insufflation is unique to endoscopic surgery and has its physiologic consequences and complications.[14,16] Conversion to open access may increase morbidity associated with the procedure and should be considered as thoracoscopic-related complications.[17]

The size of the infants may hinder proper exposure and increase the risk of complications. This limits the use of minimally invasive approaches including robotic surgery to specific weights. An anatomical difference in infants may affect trocar placement and limit the space to vital organs such as the heart and great vessels. In general, the children have relatively soft and cartilaginous and more pliable chest wall compared to the rigid chest wall of the adults, and the ribs run more horizontally to the vertebrae compared to the oblique course in the adult population. The trachea is short and narrow in the children compared to the adults, and the right bronchus is less angled. In addition, different upper airway anatomy may warrant different airway management during anesthetic management. All these anatomical factors should be considered when planning thoracoscopic surgery in the pediatric population.

Common Thoracoscopic Procedures

Lung biopsy

Lung biopsy is a simple procedure, and thoracoscopy became the preferred approach for it. Thoracoscope offers a tool to evaluate the entire surface of the lung and the pleura, but lacks tactile sense which may be required to evaluate deep lesions. Lung biopsy is essential in pulmonary fibrosis to identify its specific pathology, and it is required for tumor staging and evaluating the response to therapy.[18,19]

Preoperative diagnostic workup is essential before lung biopsy to precisely localize the lesion and identify the extent of the disease, and it includes chest radiographs and computed tomography (CT) or magnetic resonance imaging. Thoracoscopic lung biopsy has replaced thoracotomy due to the lower morbidity and mortality associated with it, in addition to the decreased hospital stay.[20] It became our standard technique for biopsy, and thoracotomy is no longer performed for this purpose.

Several techniques have been proposed to guide the surgeons to localize deep lesions during a thoracoscopic lung biopsy. These techniques include CT-guided needle localization with the application of methylene blue dye or a blood patch to mark the area overlying the lesion.[21] Other methods involve marking the lesion with a needle or microcoil labeling and intra-operative ultrasound. These localizing procedures are preferably done just before the biopsy, and a frozen section should be used to evaluate the presence of the lesion in the excised tissue.[22]

Lung biopsy is typically performed in the lateral decubitus position, and port placement should be modified according to the patient's size and the location of the lesion. Lung parenchyma can be sealed postbiopsy using endoloops or ligature, and an endostapler can be used in older children. The biopsy can be removed within an endoscopic bag or through the port depending on its size.

Diaphragmatic hernia

Diaphragmatic hernias including Bochdalek hernia can be managed using a minimally invasive approach either through laparoscopy or thoracotomy. Thoracoscopy was used first in infants with a diaphragmatic hernia and delayed presentation, then it was used for primary repair of neonatal hernia either directly or by patch repair.[23] The criteria for the successful thoracoscopic approach in neonates were reported. Neonates with the favorable lung-head ratio, no liver or stomach herniation, minimal ventilator settings, and absence of significant pulmonary hypertension had favorable outcomes.[24] Preoperative extracorporeal membrane oxygenation is not considered a contraindication to the thoracoscopic repair of the hernia.

Patients with hypoplastic lung require low pressure and low carbon dioxide (CO_2) insufflation to compress the lung; in addition, they have an acceptable working field offered by the small-sized lung. CO_2 insufflation also aids in hernia reduction, and the hernial sac does not need excision in all patients. The defect can be closed by direct nonabsorbable sutures in most cases [Figure 1]. If no posterolateral diaphragmatic border remains, a periosteal suture can be used.[25] In a survey conducted on 280 pediatric surgeons, MIS was the preferred approach for the primary repair of a diaphragmatic hernia in ≥50% of them and half of them preferred thoracoscopy for the recurrent hernia.[26]

Thoracoscopic repair of the neonatal hernia has several drawbacks, namely longer operative time compared to open repair,[17] conversion to open repair which ranges from 3% to 14%,[27,28] and recurrence of hernia (from 14% to 21%).[29]

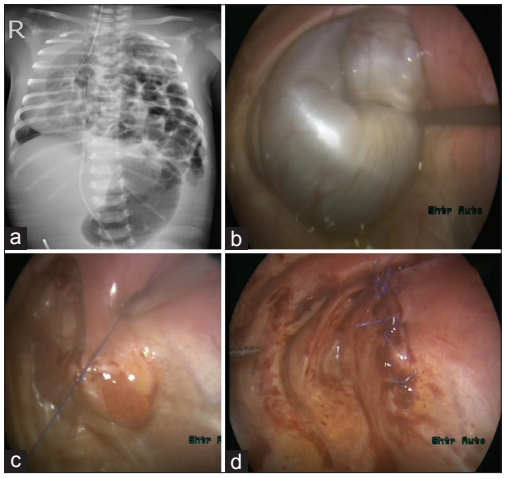

Figure 1: A case of diaphragmatic hernia repaired thoracoscopically by direct suture technique. (a) preoperative chest X-ray, (b) thoracoscopic view of the small intestine herniating to the chest cavity, (c) reduction of the intestinal content, (d) direct suture repair of the diaphragm

Ligation of the Patent Ductus Arteriosus

In a randomized trial comparing medical therapy versus ligation for the management of PDA, indomethacin therapy was associated with significant complications, and PDA ligation was the preferred approach, especially in infants with very low birth weight.[30] The thoracoscopic technique for PDA ligation was developed by Burke *et al*.[31] in Boston and Laborde *et al*.[32] in Paris in the early 1990s. The thoracoscopic approach gains popularity in many centers for PDA ligation, and it can be safely used in low weight babies, and it has the advantages of better magnification compared to the standard approach. Better magnification has a role in decreasing operative times which is vital in criterial ill patients.[33] In addition, thoracoscopic ligation offers cosmetic benefits which may have a psychological effect over the long-term follow-up, and it avoids chest tube insertion in ≥95% of the patients and consequently will lead to a shorter hospital stay.[33,34]

Esophageal Surgery

Repair of tracheoesophageal fistula and esophageal atresia can be performed thoracoscopically. Esophageal atresia repair using thoracoscopy was first performed live during the International Pediatric Endosurgery Group Meeting in 1999 in Berlin and is considered a technical breakthrough for thoracoscopic surgery.[35] Several series have followed and reported the outcomes of esophageal atresia repair associated with distal fistula.[36] Thoracoscopic repair of esophageal atresia is not suitable for all neonates, and hemodynamic instability, low body weight (<2 kg), and the inability to tolerate single-lung ventilation are considered contraindications for the procedure.[6]

In a comparison between the thoracoscopic repair and open repair of esophageal atresia; a multinational and multiinstitutional retrospective analysis of 104 patients was performed. The results of the study showed comparable outcomes and complications rate between both techniques.[35] A meta-analysis of five large series comparing open versus thoracoscopic repair showed no statistically significant difference in the complications or outcomes between thoracoscopic and the open repair.[37]

The patient is placed in the prone position with 45° tilt of the right side. Usually, the use of bronchial blockers or right mainstem bronchus intubation is not necessary. Low flow CO_2 insufflation is used to create pneumothorax which is preferred over mechanical retraction due to better pulmonary mechanics. Azygos vein division is not required in all patients, but it can be cut with diathermy. A tracheoesophageal fistula may be ligated using titanium clip, but suture ligation is preferable.

Lobectomy

Thoracoscopy lobectomy is a challenging procedure and technically demanding compared to adult lobectomy which could be attributed to the small working place or the complex nature of the lung pathology with the risk of bleeding.[38]

The indications of lobectomy for congenital lesions such as congenital lobar emphysema [Figure 2], congenital cystic adenomatoid malformations, lobar sequestration predominate in pediatric age, and lobectomy for a malignant tumor is rarely performed.[39] Nonanatomical lung resection can be performed for several lesions [Figure 3]. Prenatal ultrasound examinations have a major role in diagnosing congenital lung lesions intra-uterine. Most of these lesions are asymptomatic at birth and the question of whether they need surgery and when still debatable. Clearly symptomatic lesions necessitate surgery.[40,41] The possibility of malignant transformation and infectious complications in these lesions may argue early operation.[42] Several surgeons suggest surgery at mid-infancy.[28,43] While thoracoscopic surgery for congenital lung malformation is done in numerous centers, a study which compared the thoracoscopic versus the open surgery is limited. In a case-matched study, no significant difference between thoracoscopic versus open lobectomy as regard to the length of hospital stay, chest tube duration, and opioid requirement.[44] The feasibility and effectiveness of thoracoscopic lobectomy have been demonstrated in several studies.[2,10,19,38,39,43] The outcomes of open and thoracoscopic lobectomies are comparable in small children. The benefits of the thoracoscopic approach must be weighed against the surgeons' experience to avoid the complications of thoracoscopy in this special subset of patients.[45]

Double-lumen endotracheal tube is preferable for single-lung ventilation during the procedure. Alternatively, this can be achieved by the use of bronchial blocker or mainstem intubation of the contralateral lung, and in neonate insufflation of low flow CO_2 may be enough. In infants with a cyst that occupy a large space, it is always helpful to decompress this cyst to free more working space.[46] Thoracoscopic surgery usually starts with anterior hilar dissection then the structures are identified and ligated in a stepwise fashion from posterior to anterior or from below upward depends on which lobe to resect. Small endoscopic stapler and sealing devices are now available for vascular control. For smaller infant and neonate clips or endoloop can be used to control the bronchus.

Mediastinal Tumors and Cysts

Thoracoscopy can be used safely to resect both anterior and posterior mediastinal lesions in children with better access compared to the open approach. Posterior lesions are mainly neurogenic tumors, and they are relatively easy to excise, but the risk of bleeding is viable. Teratoma and lymphoma are commonly found in the anterior mediastinum. Preoperative imaging is essential for proper localization of the lesion and to identify its nature, and intraoperative sonography may be helpful. Several inflammatory lesions mimicking malignant lesions have been found in the mediastinum.[47] A thoracoscopic

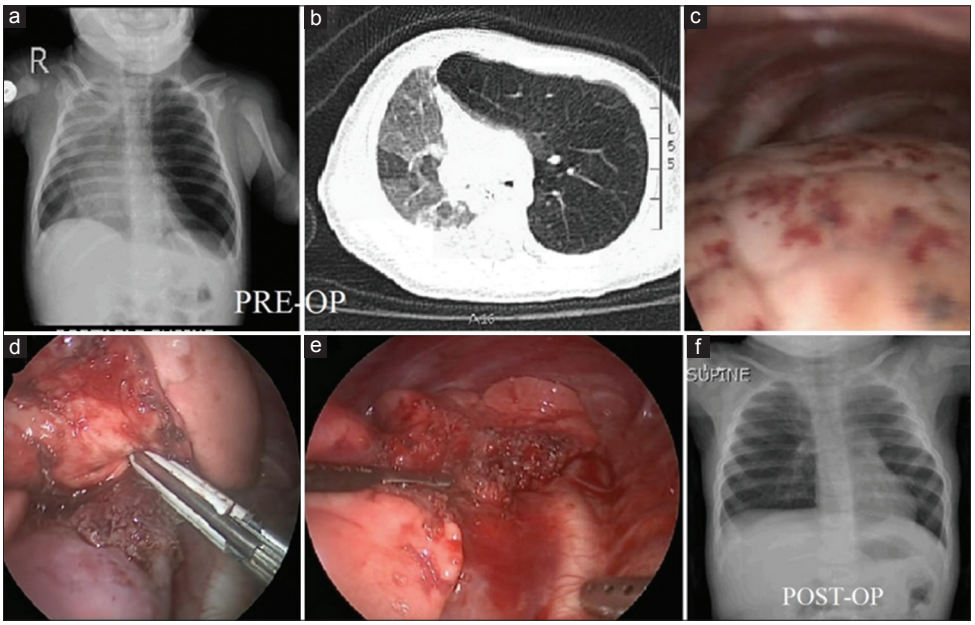

Figure 2: Congenital lobar emphysema (a) preoperative chest X-ray, (b) preoperative computed tomography scan, (c) thoracoscopic view of the distended lobe, (d and e) thoracoscopic lobectomy, (f) postoperative chest X-ray

biopsy is a preferred approach for benign mediastinal lesions in infants; however, more experience and longer follow-up are required before promoting this approach with malignant tumors.

Proper positioning is essential to provide adequate exposure. The position should allow the lung to drop away from the lesions by gravity.[48]

Empyema

Empyema is classified by the American Thoracic Society into three stages, exudative, fibrinopurulent, and organizing stage.[49] The exudative stage usually lasts 24–72 h, and fluid is thin and can be managed with chest drainage. Pus is formed in the fibrinopurulent stage, and the lung becomes less expandable. This stage usually lasts for 7–10 days up to for several weeks. The organizing stage is characterized by the formation of a membranous "peel" with fibrosis, and the lung becomes entrapped.[49] Early intervention in empyema is essential to prevent the development of the chronic stage. Drainage if adequate in the exudative stage, it is not enough to manage the fibrinopurulent stage, and thoracoscopy is recommended.[50] Thoracoscopy determines the stage of the disease, breaks the loculi, and completely evacuate the infected material. In addition, thoracoscopy provides a visual diagnostic tool for the disease of the underlying lung and the presence of bronchopleural fistula.[51] The intercostal tube is required after thoracoscopic decortication, but usually for a shorter duration than open decortication.[52] The main disadvantages of thoracoscopic decortication are the requirement of general anesthesia and surgical expertise.

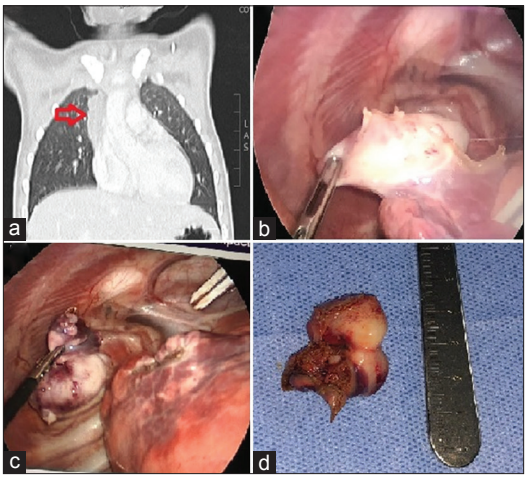

Figure 3: Thoracoscopic excision of Wilms' tumor metastasis to the right upper lobe. (a) preoperative computed tomography scan sagittal section, (b) thoracoscopic view of the tumor, (c) excision of the tumor thoracoscopically, (d) the tumor after excision

Thoracoscopy can be performed either primarily or after the failure of conventional management with intercostal drainage and antibiotics. Timing for thoracoscopic decortication is controversial, and recent results advocate early decortication before the development of a chronic stage.[53] We recommend conservative management for patients presenting in stage I and if the disease persists ≥7 days or in case of loculations, thoracoscopic intervention is recommended [Figure 4]. Thoracoscopic decortication achieved good outcomes when it is performed within 7 days of the presentation.[54] In a systematic review of 44 studies including 1369 patients, early intervention for empyema either through an open or thoracoscopic approach was associated with a shorter

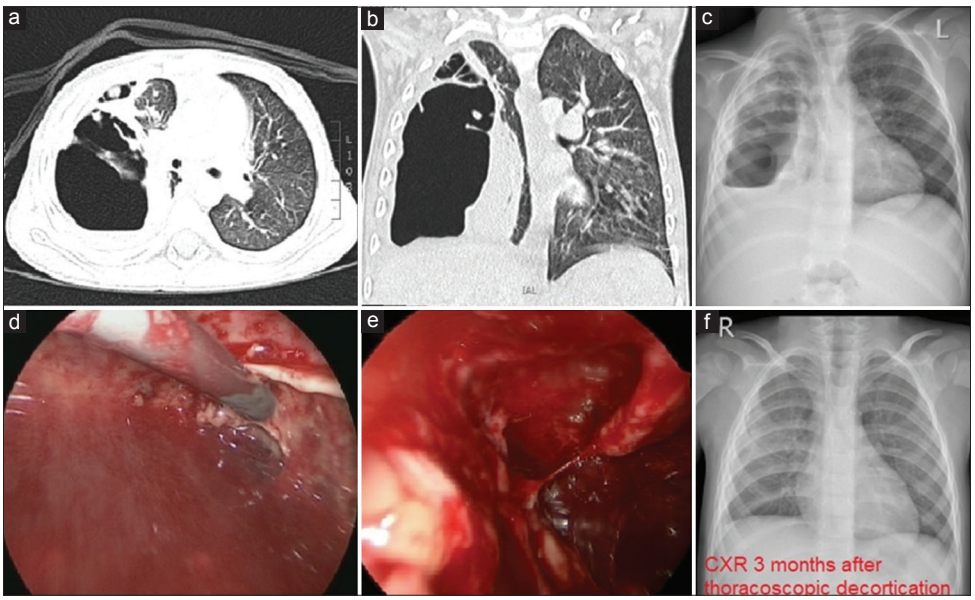

Figure 4: Thoracoscopic decortication. (a and b) preoperative computed tomography scan, (c) preoperative chest X-ray, (d) thoracoscopic view of the thickened pleura, (e) thoracoscopic cutting of the adhesions, (f) chest X-ray 3 months after decortication

length of stay, but no difference between thoracoscopic and conventional decortication. The current practice integrates both thoracotomy and thoracoscopy for the management of empyema in children.[50]

Points to Consider for Thoracoscopy

Cosmetic aspects are very essential in thoracoscopic surgery. Single-lung ventilation using a double-lumen endotracheal tube should be considered for thoracoscopic lobectomies in older children, and bronchial blockers are alternatives. However, in small children low pressure CO_2 insufflation should be sufficiently provided no desaturation occurs.[55]

Pain is less frequently reported after thoracoscopy compared to thoracotomy, and usually, it is related to port incisions. Local infiltrating anesthesia at the site of trocar insertion before the closure is helpful to control postoperative pain. An intercostal nerve block can also be done under direct visualization at the conclusion of the procedure.[56]

The recommended CO_2 insufflation pressure is 5 mmHg which has minimal hemodynamic effects.[57] Higher pressure may cause hemodynamic compromise and myocardial ischemia; therefore, an open approach is preferred for a patient with cardiac comorbidities.

Several thoracoscopy-related complications are due to lack of the appropriate experience. Early training and close supervision are essential to avoid problems related to the learning curves.

The surgical approach should be tailored based on the patients' size and age and the target structure.

Bleeding is of special importance during thoracoscopy because bleeding control can be problematic. Bleeding can be managed either by open conversion or identifying the bleeding site and clipping or cauterization under direct vision. Avoid blind clipping or cauterization as it may lead to serious injury to vital structures.

Vigorous manipulation during the extraction of the specimen from the chest cavity should be avoided as it can lead to dissemination of infection or implementation of malignant cells on the chest wall. Removal of tissues can be through an endobag for large specimen or direct for the small-sized specimen.

Triangulation should be considered during port placement to provide enough working space. Attention should be paid to avoid liver or diaphragmatic injury during replacement of the lower port. Insert the ports using blunt dissection and use the first port to inspect the cavity for any injury implicated after port placement, and subsequent ports should be placed under direct vision. Inspect the trocar site for bleeding after removal of the ports. Foley catheter can be used to tamponade the bleeding if encountered after trocar removal.

Postoperative subcutaneous emphysema has no clinical impact and usually resolves within a few days.

Serrated ports or suturing ports to the chest wall can prevent easy dislodgement of the ports in small or thin children. If postoperative bleeding or air leak are anticipated, insert a chest tube. Otherwise, use suction through the last port and ask the anesthesiologist to keep the lung expanded until the closure is completed.

Thoracoscopy is used in different surgical procedures in the pediatric population. Various complications were reported [Table 1], and careful planning and training are required for better outcomes. The field is evolving with new researches, and techniques are continuously published [Table 2].

Conclusion

Thoracoscopy became an indispensable tool in thoracic surgery. Clinical randomized trials comparing it to the standard approach are deficient. Studies confirmed the feasibility of thoracoscopy in specific procedures in children. The thoracoscopic instruments are still evolving, and the body weight and size are no longer contraindications to this approach.

The cosmetic advantages of thoracoscopy were confirmed; in addition, it decreases postoperative pain and surgical

Table 1: Complications of thoracoscopy for lung resection in children

Study	Procedure and number	Bleeding (%)	Air leak (%)	Other complications (%)
Unpublished author data	Lobectomy (*n*=21)	0	2 (3.5)	1 (1.8) wound infection
	Lung biopsy and metastasectomy (*n*=35)			1 (1.8) phrenic nerve injury 1 (1.8) conversion
Rothenberg *et al*., 2011[58]	Lobectomy (*n*=75)	2 (2.67)	2 (2.67)	3 (4) infection
Boubnova *et al*., 2011[59]	Lobectomy (*n*=16)	0	1 (6.25)	1 (6.25) phrenic nerve injury
Zhang *et al*., 2018[60]	Lobectomy (*n*=128)	-	-	1 (0.7) conversion
Rothenberg *et al*., 2015	Lobectomy (*n*=347)	-	3 (0.9)	3 (1) conversion
Seong *et al*., 2012[61]	Lobectomy (*n*=37)	1 (2.7)	2 (5.4)	8 (23) conversion

Table 2: Summary of recent studies in different thoracoscopic procedures in pediatrics

Author	Year	Number	Summary/objective
		Lung biopsy	
Nadlonek *et al.*[62]	2014	90 patients	To determine the effectiveness of intraoperative chest tube removal
Gamba *et al.*[63]	2010	18 patients	To study the results of lung biopsy in severely compromised patients
		Diaphragmatic hernia	
Poupalou *et al.*[64]	2018	Case report	A new technique for patch fixation to reinforce the mesh after congenital diaphragmatic hernia repair
Bruns *et al.*[26]	2016	Survey on 280 pediatric surgeons	To study surgical strategies for management of recurrent diaphragmatic hernia
Liem *et al.*[65]	2011	139 patients	Presents the indications and surgical details for diaphragmatic hernia repair
		Esophageal surgery	
Wu *et al.*[66]	2017	447 patients from 10 studies	A meta-analysis comparing open approach versus thoracoscopy for esophageal atresia
Ehlers *et al.*[67]	2015	3 patients	Use of jet ventilation during tracheoesophageal fistula repair
		Lobectomy	
Moyer *et al.*[68]	2017	review	The authors described their lobectomy technique with literature review for lobectomy in congenital lesions
Park *et al.*[69]	2017	265 patients	Evaluate the learning curve for thoracoscopic lobectomy in children
		Mediastinal surgery	
Souzaki *et al.*[70]	2018	5 patients	To evaluated muscle sparing axillary skin crease incision in patients with mediastinal lesions
Scarpa *et al.*[71]	2018	Total 41 patient, 27 of them had thoracoscopy	To report authors' experience with resection of foregut duplication cyst
		Empyema	
Dorman *et al.*[72]	2016	5569empyemapatientsmanagedby different techniques	The study showed a decrease in the trend of thoracoscopy in empyema
Livingston *et al.*[73]	2016	67 empyema patients; 28 had thoracoscopy	A clinical trial comparing thoracoscopy to chest tube plus fibrinolysis with similar outcomes

site complications. Proper training is essential as it affects the outcomes and conversion rate and enhances the ability to manage the complications thoracoscopically. Conversion should not be considered as treatment failure, and its possibility should be explained to the patients/parents and stated clearly in the consent.

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Conflicts of interest
There are no conflicts of interest.

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