Thoracoscopic operations in children

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A video of thoracoscopic operation is available at <www.hkmj.org>.

A B S T R A C T

Over the past two decades there has been an exponential growth in the use of thoracoscopy in children. Indeed, many advanced procedures—including lobectomy, repair of tracheoesophageal fistula, excision of mediastinal tumours, and diaphragmatic hernia repairs—can now be performed by this means in advanced paediatric surgical centres in the world. This review describes the historical perspectives and the current state of thoracoscopic surgery, including potential benefits and challenges, in children.

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Introduction

Minimally invasive surgery is considered one of the most important milestones in surgery in recent decades. In this regard, operating in the thoracic cavity of children has changed drastically from an open approach to a completely thoracoscopic procedure in just a little over 30 years. In paediatric patients, thoracoscopic procedures had once been regarded as a 'state of the art' practice, but are now the standard of care for many disease conditions in advanced paediatric surgical centres. In this review, we describe their development for children and their current status.

Historical perspective

The concept of thoracoscopy was first introduced more than a hundred years ago by a Swedish physician, Hans Christian Jacobaeus. In 1910, he reported his initial experience after inserting a cystoscope into the pleural cavity to perform lysis of a tuberculous pleural adhesion as part of the treatment. But it was not until almost 70 years later in 1976, when Rodgers and Talbert[1] put thoracoscopy into first practical use for paediatric patients. At this early stage, thoracoscopic procedures in children were only limited to lung biopsies, evaluation of thoracic or pulmonary lesions, and regional decortication of an empyema.[2] Despite increasing recognition of its potential advantages, it did not gain widespread acceptance or popularity owing to technical and anaesthetic difficulties.

The first laparoscopic cholecystectomy in 1985 by Mühe[3] was a turning point that brought about a revolutionary change in this type of surgery. This ensuing exponential growth in the development of minimally invasive surgical procedures also stimulated the technological advances pertaining to associated surgical instruments, including the development of high-definition digital cameras, smaller-calibre instruments, and new energy-delivering devices. This meant that surgeries could be performed in smaller children more safely and effectively, and in a minimally invasive manner. The experience and skills gained from laparoscopic surgeries, together with improvements in anaesthetic techniques, enabled paediatric surgeons to venture into the thoracic cavity.

Advantages and difficulties

Cosmetic superiority is the most obvious advantage provided by thoracoscopic operations (Fig 1). Smaller incisions not only meant that postoperatively there could be much smaller and almost invisible surgical scars, but more importantly the pain associated with traditional thoracotomy was greatly reduced. As a result of such extreme facility, some centres are now performing minor thoracoscopic procedures on an out-patient basis.[4] In addition, the significant decrease in overall wound lengths and tension reduced the risks of wound infection and dehiscence,[5] which were associated with shorter hospital stays and earlier recovery.[6,7]

The most dreaded and well-known long-term complications of thoracotomy are musculoskeletal. They include chest wall deformities, rib fusion, shoulder girdle weakness and scoliosis, and can occur in up to 30% of patients undergoing thoracotomy.[8,9] The mechanism underlying these problems is related to the division of shoulder girdle muscles such as the latissimus and serratus, and often resulted in girdle weakness. Furthermore, the tensile forces created by thoracotomy wound closure over the ipsilateral chest wall could distort the thoracic cage as the child grows.[10] In contrast, these complications are virtually non-existent in patients who undergo thoracoscopic procedures.[11]

Thoracoscopic operations enable surgeons to enjoy superior surgical visibility and precision. With the aid of high-definition monitors and cameras, the smallest structures including blood vessels and nerves can now be visualised under magnification (Fig 2), which allowed surgeons to dissect with greater precision and thus avoid unintentional injuries. Another advantage of thoracoscopy is provided by telescopes with viewing angles that enable easy evaluation of the whole thoracic cavity and the entire lung surface from a limited port access. As a result, even the most deep-seated areas and corners can now be seen clearly, which was previously not possible during conventional thoracotomies.

Everything comes at a price, and thoracoscopic surgery is no exception. First, there are the challenges encountered across the spectrum of minimally invasive surgery in general, and include lack of three-dimensional vision, reduced feedback from tactile sensation, and the protracted learning curve for paediatric thoracoscopic surgeons. One reason for the latter was the body size of our patients. Since a young child with only half the height of an adult provides one-eighth the working thoracoscopic space, the difficulties encountered in manipulating instruments inside the thorax of a neonate are obvious. Second, apart from the limitation of working space (always a concern for paediatric surgeons), the ability to achieve adequate single-lung ventilation was also a limitation. This was partially solved by creating more space, as well as the development of smaller instruments that allowed finer and more ergonomically friendly movements. Third, the variation in body size among paediatric patients also made the learning process difficult. Surgeons had to adapt from a 3-kg neonate to a 70-kg teenager, before they could truly master all the necessary skills, which also imposed a significant effect on the length of the learning curve.

Safe control of major vasculature and other passages remains a major challenge even for experienced surgeons, especially in the case of thoracoscopic lobectomy. Unlike adults, in whom the endoscopic stapler can be employed to take control of the pulmonary vessels and bronchi, this device often proves too large to be used in children, as a 12-mm trocar port and at least 5 cm of intrathoracic space are required for it to open fully.[12] New sealing devices—such as LigaSure (Covidien, US), EnSeal (Ethicon, US), and Thunderbeat (Olympus, Japan)—allow safe sealing of the main pulmonary vessels up to 7 mm in diameter and thus they have replaced resorting to endoclips, which may dislodge during dissection or obscure satisfactory tissue dissection

兒童胸腔鏡手術的應用

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在過去二十年，胸腔鏡在小兒外科手術中的使用與日漸增。事實上，在世界各地一些先進的小兒外科中心內已經可以利用胸腔鏡進行很多較為困難和複雜的手術，包括肺葉切除術、縱隔腫瘤切除術、修復氣管食管瘺和膈疝修復。本文簡述胸腔鏡應用在小兒外科手術的歷史及現況，並討論其潛在優點和所面對的挑戰。

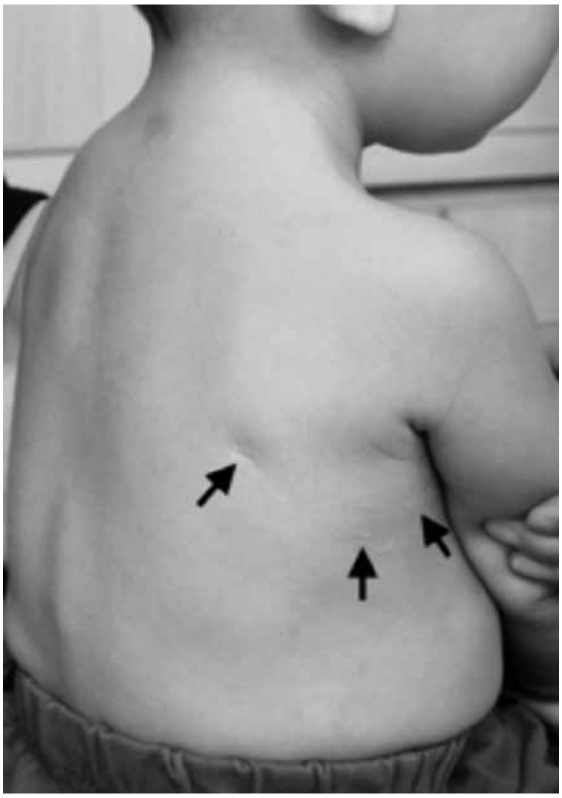

FIG 1. A clinical photograph of a child after thoracoscopic operation with minimal scars (arrows)

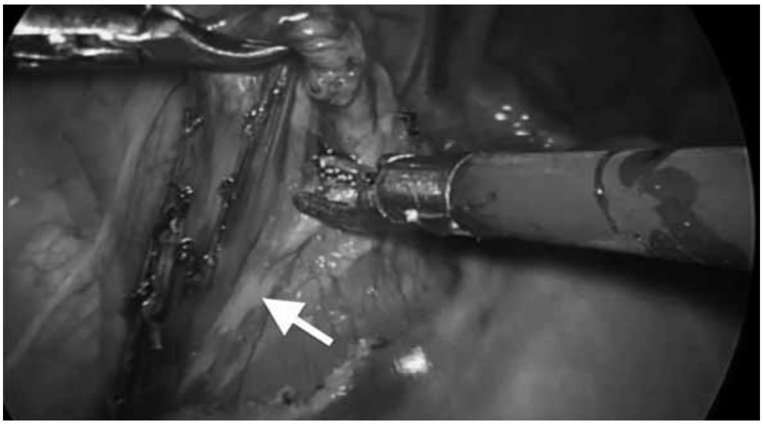

FIG 2. An intra-operative photograph during thoracoscopic excision of oesophageal duplication cyst. This shows an excellent view of the vagus nerve (arrow)

due to the space they occupy. These energy-sealing devices also diminish technical difficulties during the performance of complex lobectomies, as they are proven to be safe and efficient in sealing off lung tissues and dividing incomplete fissures.[13] Nonetheless, a complete understanding of the three-dimensional anatomical relationships and precision in tissue dissection is still the key to success.

Anaesthetic aspects

Paediatric thoracoscopic surgery is not only about surgical and technical refinements. Anaesthetic techniques play a major role in achieving successful thoracoscopic surgery. To create adequate thoracic space for efficient surgery with good exposure, single-lung ventilation is a prerequisite in the surgical management of many thoracic conditions. Unlike adults in whom single-lung ventilation can be easily performed using a double-lumen endotracheal tube, this is not feasible in young children. The smallest double lumen tube is a 26F, and may even be used for children younger than 8 years old. For even smaller patients, standard endotracheal intubation together with insertion of an endobronchial blocker in the ipsilateral bronchus of the operated lung or selective intubation of the contralateral bronchus with an endotracheal tube turn out to be the solution. An endobronchial blocker is a catheter-like device with a balloon attached to its tip for occlusion and contains a central stylet. Depending on the size of the patient, under fibre-optic bronchoscopic guidance, the endobronchial blocker is placed either within or outside the lumen of the endotracheal tube and advanced into the main stem bronchus of choice. The balloon is then inflated to create bronchial occlusion under direct vision. Problems with bronchial blockers include dislodgement of the blocker balloon into the trachea with blockade of ventilation, and overdistention of the balloon leading to damage of the airway. With selective intubation of the contralateral main stem bronchus, an uncuffed endotracheal tube around half to one size smaller than the usual is selected for advancement into the main stem bronchus under fibre-optic bronchoscopic guidance. Problems with selective main stem intubation include difficulty providing adequate seal, obstruction of the upper lobe bronchus, and inability to provide suction for the operative lung.[4] Both of these techniques have produced single-lung ventilation with satisfactory result.[14]

After successful establishment of single-lung ventilation, lung collapse can be enhanced further by carbon dioxide insufflation into the thorax. This is particularly helpful in the event the endobronchial tube is not totally occlusive resulting in a degree of overflow ventilation. Carbon dioxide infusion at low pressure (4 mm Hg) and low flow (1 L/min) helps keep the lung compressed during the surgery and reduces the risk of injury from using a retractor. Maintenance of this low-setting environment requires the use of valved trocars.

The safety of single-lung ventilation in paediatric patients had been a major concern. Although there was a previous report on mucosal or bronchial injury during intubation,[14] several recently reported large series [15-17] have demonstrated the safety and efficacy of single-lung ventilation in children, without major complications or mortality. Dingemann et al[18] compared children having single-lung ventilation and those having conventional two-lung ventilation. They found no statistically significant difference between the groups in terms of the timing of extubation, the rate of postoperative atelectasis or pneumonia, and the length of intensive care unit stays.

Increased compression of the dependent lung in the lateral decubitus position, surgical retraction and single-lung ventilation with collapse of the operative lung can aggravate ventilation-perfusion mismatch. Intra-operative hypercapnia and acidosis

TABLE 1. Conditions with thoracoscopic procedures reported in the literature

Condition	Thoracoscopic procedure
Achalasia	Cardiomyotomy
Bronchogenic cyst	Excision
Bronchopulmonary sequestration	Resection
Chylothorax	Thoracic duct ligation
Congenital cystic adenomatoid malformation	Lobectomy
Diaphragmatic eventration	Diaphragmatic plication
Diaphragmatic hernia	Hernia repair
Diaphragmatic rupture	Diaphragmatic repair
Empyema	Decortication
Lobar emphysema	Lobectomy
Lung tumour	Biopsy +/- excision
Mediastinal tumour	Biopsy +/- excision
Myasthenia gravis	Thymectomy
Oesophageal atresia +/- trachea-oesophageal fistula	Repair +/- closure of fistula
Oesophageal diverticulum	Excision
Oesophageal duplication cyst	Excision
Oesophageal stenosis	Oesophagectomy +/- conduit reconstruction
Palmar hyperhidrosis	Sympathectomy
Patent ductus arteriosus	Ligation
Pectus excavatum	Nuss procedure
Pericardial cyst	Excision
Pericardial effusion	Pericardial fenestration
Pneumothorax	Pleurodesis +/- bullectomy
Spine deformity	Anterior spinal fusion
Tracheomalacia	Aortopexy

TABLE 2. Summary of major studies on selected thoracoscopic procedures[7,18,20,21,24,27-29,31-70]

Disease group	Author(s)	Year	Study design	Study type	No. of thoracoscopic procedures
Empyema	Aziz et al[31]	2008	Retrospective	Case control	28
	Chiu et al[32]	2006	Retrospective	Case control	11
	Freitas et al[33]	2009	Retrospective	Case series	99
	Gates et al[34]	2004	Retrospective	Case control	Not mentioned
	Kurt et al[35]	2006	Prospective	Randomised trial	10
	Padman et al[36]	2007	Retrospective	Case control	50
	St Peter et al[37]	2009	Prospective	Randomised trial	18
	Tsao et al[38]	2008	Retrospective	Case series	79
	Wong et al[39]	2005	Retrospective	Case control	49
Pneumothorax with lung bulla	Bialas et al[40]	2008	Retrospective	Case series	41
	Choi et al[41]	2013	Retrospective	Case series	126
	Chung et al[24]	2009	Retrospective	Case series	15
	Ozcan et al[42]	2003	Retrospective	Case series	32
	Qureshi et al[43]	2005	Retrospective	Case control	34
Congenital lung lesions	Bonnard et al[44]	2004	Retrospective	Case control	3
	Bratu et al[45]	2005	Retrospective	Case control	11
	Diamond et al[46]	2007	Retrospective	Case control	12
	Kunisaki et al[47]	2014	Retrospective/ prospective	Cohort	49
	Lau et al[7]	2013	Retrospective	Case control	39
	Rahman and Lakhoo[48]	2009	Retrospective	Case control	14
	Rothenberg et al[49]	2011	Retrospective	Case series	75
	Tölg et al[50]	2005	Retrospective	Case control	4
	Vu et al[51]	2008	Retrospective	Case control	12
Oesophageal atresia +/- trachea-oesophageal fistula	Al Tokhais et al[52]	2008	Retrospective	Case control	23
	Allal et al[28]	2009	Retrospective	Case control	14
	Dingemann et al[18]	2013	Retrospective	Case control	22
	Holcomb et al[53]	2005	Retrospective	Case series	104
	Huang et al[29]	2012	Retrospective	Case series	33
	Lugo et al[54]	2008	Retrospective	Case control	8
	MacKinlay[55]	2009	Retrospective	Case series	26
	Nguyen et al[56]	2006	Retrospective	Case series	6
	Rothenberg[57]	2013	Retrospective	Case series	52
	Szavay et al[27]	2011	Retrospective	Case control	25
	van der Zee et al[58]	2012	Retrospective	Case series	72
Congenital diaphragmatic hernia	Arca et al[59]	2003	Retrospective	Case series	7
	Becmeur et al[60]	2007	Retrospective	Case series	14
	Cho et al[61]	2009	Retrospective	Case control	29
	Fishman et al[20]	2011	Retrospective/prospective	Cohort	12
	Gander et al[62]	2011	Retrospective	Case control	35
	Gomes Ferreira et al[63]	2009	Retrospective	Case series	18
	Gourlay et al[64]	2009	Retrospective	Cohort	20
	Keijzer et al[65]	2010	Retrospective	Case control	23
	Kim et al[66]	2009	Retrospective	Case series	15
	Lao et al[67]	2010	Retrospective	Case control	14
	McHoney et al[21]	2010	Retrospective	Case control	13
	Okazaki et al[68]	2011	Prospective	Cohort	8
	Szavay et al[69]	2012	Retrospective	Case control	17
	Yang et al[70]	2005	Retrospective	Case series	7

associated with thoracoscopic procedures have been well documented.[19-21] It has been postulated that hypercapnia and acidosis are caused by the use of carbon dioxide as the insufflation agent, increasing carbon dioxide absorption into the systemic circulation. Based on a pilot randomised controlled trial, Bishay et al[22] has confirmed the presence of prolonged hypercapnia in thoracoscopic surgery patients compared to those having open thoracotomy, but the long-term consequence of this finding was unclear.

Selected conditions

Thus far, thoracoscopy has been reported to be the surgical approach in more than 20 types of thoracic conditions in children and infants (Table 1). As there are neither absolute contra-indication nor guidelines on which thoracic condition should or should not be performed thoracoscopically, this means that virtually all chest condition can be managed in this manner.

Thoracic empyema was the first condition in which the thoracoscopic approach was deployed. Early thoracoscopic decortication following the failure of initial conservative treatment with chest tube drainage and antibiotics is now recommended.[23] In most patients, primary spontaneous pneumothorax has been shown to be related to underlying lung bullae.[24] These can be managed by thoracoscopic bullectomy without the need for prolonged chest tube drainage and hospitalisation, which is in contrast to simple conservative management. Moreover, it has evolved to become the standard treatment in many regional centres. Likewise, thoracoscopic lung biopsy has been widely used as a diagnostic tool in interstitial lung disease or for intrathoracic tumour, and some centres even advocate these to be performed as day-case procedures.[25]

The most commonly performed thoracoscopic operation in young infants is for congenital cystic lung disease. The condition consists of congenital cystic adenomatoid malformations, bronchopulmonary sequestration, bronchogenic cysts, and congenital lobar emphysemas. With the increasing use of antenatal ultrasonography during routine follow-up, there has been a significant increase in the reported incidence of this disease. Thoracoscopic resection or lobectomy is usually recommended at 6 months of age, in view of the risks from frequent pneumonia and the potential for future malignancies.

Centres with experience have now pushed the application of paediatric thoracoscopic surgery towards the treatment of neonatal conditions. Ever since the first successful case of thoracoscopic repair of oesophageal atresia in 1999,[26] the procedure has been labelled as the 'pinnacle of paediatric surgery'. Due to its difficulty, only a few small series (including ours) have been published and the initial results are encouraging.[27-29] Repair of Bochdalek's congenital diaphragmatic hernia is also routinely managed using the thoracoscopic approach. Due to the underlying pulmonary hypoplasia, the thoracic cavity on the affected side provides excellent working space, for which single-lung ventilation may not be necessary and only very-low-pressure low-flow carbon dioxide insufflation is all that is required.[30] Table 2[7,18,20,21,24,27-29,31-70] provides a brief summary of the major studies dealing with the aforementioned conditions.

Conclusion

Thoracoscopic surgery in children has come a long way since its inception. There is solid evidence supporting its safety and applicability in routine clinical use. More prospective studies are required to determine whether it offers genuine advantages over traditional open surgery.

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