Use of the Arndt Wire-Guided Endobronchial Blocker to Facilitate One-Lung Ventilation for Pediatric Empyema during Video-Assisted Thoracoscopy

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Background: Video-assisted thoracoscopic surgery (VATS) has emerged as an innovative and popular procedure for the management of postpneumonic empyema in children refractory to a medical response. One-lung ventilation is required during VATS. In this study, we evaluated the efficacy of intraoperative wire-guided endobronchial blockade (WEB) for achieving 1-lung ventilation during a thoracoscopic procedure for pediatric empyema.

Methods: Eighteen patients undergoing a VATS approach for evacuation of an empyema cavity were studied. We used a new device, a bronchial blocker tube, to establish 1-lung ventilation. Intraoperative oxygenation, ventilation, and hemodynamics, as well as the duration of the operation during 1-lung ventilation were recorded. The number of unsuccessful placement attempts, number of malpositionings of the device, and the number of secondary dislodgements of the device after turning the patient into the lateral position were also counted. The quality of lung deflation and inflation was rated by the surgeon under direct visualization as either excellent, fair, or poor.

Results: The mean operative time was 80 ± 10.8 (range, 50~120) min. The mean peak inspiratory pressure under 1-lung ventilation was 28.7 ± 3.6 cmH_2O, and no desaturation was noted. A number of unsuccessful placement attempts were required in 1 patient (1/18) for left-sided VATS. No malpositioning or secondary dislodgement of the device was noted. The quality of lung deflation was judged as being excellent in all patients.

Conclusions: VATS can safely and effectively be performed in children with a proper anesthetic technique. With the development and clinical use of this new device, the bronchial blocker tube proved to be effective and easy to use for establishing 1-lung ventilation in a pediatric population.

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Key words: wire-guided endobronchial blockade, 1-lung ventilation, video-assisted thoracoscopy.

Thoracic empyema affects a large number of children with significant morbidity, mortality, and consumption of hospital resources if not recognized promptly or treated appropriately. Surgical treatment

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of postpneumonic empyema is essential for children with an unsatisfactory medical response. The advent of video-assisted thoracoscopic surgery (VATS) has emerged as an innovative and popular procedure for the evacuation and drainage of postpneumonic empyema in pediatric patients.[1,2] One-lung ventilation and alternative uses of 2-lung ventilation are needed during this surgery. There are several methods to achieve this. In adults, 1-lung ventilation is most commonly achieved with a double-lumen tube[3,4] or a Univent tube.[5,6] However, because of the unavailability of double-lumen tubes and Univent tubes for small children, a bronchial blocker and a single-lumen endobronchial tube are currently used for lung separation in pediatric populations. Although a single-lumen tube for endobronchial intubation enables 1-lung ventilation, it is a challenge for the anesthesiologist when alternate requirements for bilateral-lung ventilation and 1-lung ventilation exist during surgery. This study was designed to evaluate the efficacy of an intraoperative wire-guided endobronchial blockade (WEB), a new tool for achieving 1-lung ventilation and which is also used during thoracoscopic procedures for pediatric empyema and pleural decortication.

METHODS

Following ethical approval and the acquisition of written, informed consent, 18 children (12 girls and 6 boys) with postpneumonic empyema undergoing VATS adhesiolysis, pleural debridement, and irrigation were studied. Empyema was confirmed in all parapneumonic effusion patients, mainly through chest radiography and chest computed tomography. Empyema was diagnosed in cases where there was a positive Gram's stain or when frank pus was aspirated from the pleural cavity. All of these patients received antibiotics and closed chest tube drainage as their primary therapy after their initial diagnostic thoracocentesis. All children referred for surgery had unsatisfactory medical responses, with persistent bronchopleural fistulae, unremitting fever, tachypnea, chest pain, sepsis, localized empyema, and persistent lung collapse despite chest tube drainage.

All patients were taken to the operating room without premedication. Noninvasive arterial blood pressure, electrocardiography, pulse oximetry, capnography, and body temperature were routinely monitored. Following preoxygenation, anesthesia was induced with intravenous administration of fentanyl (5 μg/kg), and midazolam (0.1 mg/kg). Vecuronium bromide (0.1 mg/kg) was administered to facilitate endotracheal intubation. The vocal cords were exposed by direct laryngoscopy, and orotracheal intubation was performed with an endotracheal tube sized according to the age of the child. An Arndt WEB (Arndt endobronchial blocker set, Cook Critical Care, Bloomington, IL, USA) was placed coaxially through the endotracheal tube using a pediatric bronchoscope and a special bronchoscopic port (Fig. 1). The special bronchoscopic port offers multiple access ports. The proximal end of the endotracheal tube was attached to a multiport adapter that allows the simultaneous introduction of the bronchoscope and the endobronchial blocker while maintaining ventilation of the lungs. The endobronchial port (WEB port), which is oriented at 30° to the bronchoscopic port, has a Tuohy-Borst-type valve that locks the blocker in place and maintain an airtight seal. Prior to placement of the WEB, the elliptical balloon of the blocker must be deflated. Through fiberoptic bronchoscopic (FOB) guidance, the blocker was advanced until it could be seen below the single-lumen tube, and then the fingertips were twirled until the distal tip entered the right or left main bronchus. The elliptical balloon of the blocker was inflated

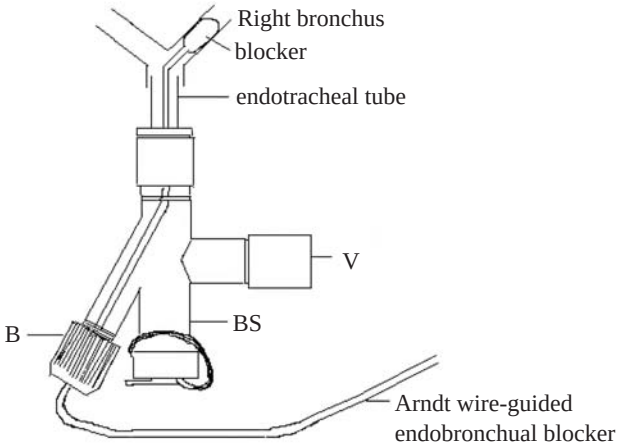

Fig. 1 Illustration of an Arndt wire-guided endobronchial blocker via an endotracheal tube and the special bronchoscopic port with a ventilation port (V), bronchoscopic port (BS), and blocker port (B).

under direct visualization, and the FOB was withdrawn. Lung separation was accomplished without difficulty through inflation of the blocker balloon.

Anesthesia was maintained with fentanyl (5 μg/kg/h), isoflurane (0.5%~1.5%) in oxygen, and vecuronium (0.1 mg/kg/h). A radial arterial line was inserted for continuous monitoring of blood pressure and arterial blood gas analysis. Volume-controlled ventilation was performed with the fraction of inspired oxygen F_iO_2 at 0.5; an inspiratory-to-expiratory (I:E) ratio of 1: 2; and a tidal volume of 10 ml/kg at a ventilatory rate of 12~18 beats/min during 2-lung ventilation. Ventilatory settings were kept constant during the study. F_iO_2 was increased to 1.0 with initiation of 1-lung ventilation. After initiation of 1-lung ventilation, the alveolar recruitment strategy of the dependent lung was carried out by increasing the peak inspiratory pressure to 40 cmH_2O, together with a PEEP of 10 cmH_2O for 10 respiratory cycles. Five minutes later, arterial blood-gas analysis was performed in all patients, and peak inspiratory airway pressures were simultaneously recorded. All patients were placed in the lateral decubitus position. A thoracoscopic examination was accordingly carried out, and total collapse of the affected lung was confirmed by direct vision. All purulent tissue and fibrin peel within the pleural cavity and the lung parenchyma were evacuated thoracoscopically, and the infected necrotic lung tissue was excised and removed.

After the total pneumonolysis was performed, the surgeon requested re-expansion of the collapsed lung and suctioning of the affected airway to ensure complete expansion of the entire lung parenchyma. The elliptical balloon of the blocker was deflated to establish 2-lung ventilation. F_iO_2 was maintained at 1.0 during 2-lung ventilation. Positive-pressure ventilation with 10 cmH_2O PEEP was applied to re-expand the affected lung. Peak inspiratory pressures were recorded after 2-lung ventilation was established. If the peak airway pressure exceeded the basal values during 2-lung ventilation by 30%, the tidal volume was reduced to 8 ml/kg, the inspiratory pause was zeroed, and the I:E ratio was increased to 1:1. A suction catheter was placed in the tube to prevent overflow from 1 main bronchus into the other when the balloon blocker was deflated. The affected lung expansion was witnessed through direct vision by the surgeon. If the lung was coated in fibrin peel and did not expand, the surgeon again requested 1-lung ventilation by inflating the bronchial blocker balloon. The procedure was repeated several times during surgery. Thoracoscopic decortication was subsequently performed.

When the surgery had been concluded and the bronchial blocker was no longer needed, it was removed. After surgery, the patients were sent to the intensive care unit with the endotracheal tube in place for postoperative care. The endotracheal tube was removed on the second to fourth postoperative days. The chest tube was removed when air leakage had stopped and chest radiography revealed full lung expansion. Patients were discharged following removal of the chest tube.

RESULTS

These patients ranged in age from 8 months to 15 years (mean age 6.5 ± 3.5 years). Ten patients underwent right thoracoscopy and 8 patients had the procedure performed on the left side. In all patients, selective 1-lung ventilation was successfully achieved. The right bronchus was easily collapsed by the bronchial blocker for right-sided VATS in all patients. Unsuccessful placement attempts occurred in 1 patient (1/18) for left-sided VATS. No malpositioning or secondary dislodgement of the device after turning the patient into the lateral position was noted. The quality of lung deflation was judged to be excellent in all patients.

The technique provided a motionless collapsed lung for thoracoscopy, which improved the surgical exposure. Selective bronchial blocker intubation succeeded in isolating the diseased from the healthy lung, thus preventing any possible transbronchial spread of contaminated empyematous fluid to the dependent normal lung. There was no deterioration in the heart rate or mean arterial pressure during 1-lung ventilation. The mean peak inspiratory pressure under 1-lung ventilation was 28.7 ± 3.6 cmH_2O, and no desaturation was noted throughout the entire procedure (Table 1). The quality of lung deflation and inflation was judged to be excellent in all patients during the 1-lung and 2-lung ventilation procedures. There was no anesthesia-related morbidity.

Thoracoscopic debridement and irrigation were successfully completed in all patients. None of the patients required conversion to an open thoracotomy,

and there was no procedure-related morbidity or mortality. Sixteen patients were extubated on the second postoperative day; the other 2 patients were extubated 4 days after the operation. Postoperative fiberoptic bronchoscopy follow-up revealed no abnormalities in the dependent main bronchus. The mean postoperative hospital stay was 13.5 (range, 9~21) days.

DISCUSSION

Pediatric empyema encompasses a spectrum of inflammatory manifestations ranging from thin parapneumonic pleural effusion to the formation of a thick, constricting rind. The main focus of treatment for this suppurative process continues to be early evacuation of the loculated pus. Pediatric patients with empyema that experience an unsatisfactory medical response are often considered for surgical intervention as early as possible to avoid subsequent potentially fatal complications.

Various reports have proposed VATS as a treatment for empyema in children in order to avoid the morbidity of open surgical drainage, to allow prompt clinical resolution of symptoms, and to prevent sequelae associated with delayed management.[1,2] Due to recent advances in the VATS technique, patients with pleural and thoracic disorders can now be managed less invasively.[7,8] VATS requires 1-lung ventilation with a properly collapsed lung. If the operation is performed without selectively blocking the bronchus of the affected lung, there is a possibility that the trachea and the dependent lung may be contaminated or flooded with the contents of the abscess cavity during manipulation of the diseased lung.[9] Flooding of the trachea and dependent lung may acutely impair ventilation and lead to inflammation and abscess formation in the dependent lung. One-lung ventilation is indicated when isolation of 1 lung is necessary to prevent contamination by secretion or blood in the other lung, or to provide adequate ventilation to the healthy lung. In adults, there are several options for isolating both lungs. These include a double-lumen tube,[3,4] a Univent tube,[5,6] and bronchial blockade with a Fogarty arterial embolectomy catheter,[10] a pulmonary catheter,[11] a urinary catheter,[12] and even a single-lumen endobronchial tube. However, Univent tubes or double-lumen endobronchial tubes are too large to be used in most small children. Thus, in an infant or child, 1-lung blockage is commonly achieved using a single-lumen endobronchial tube or a bronchial blocker.[13]

Table 1. Effect of 1-Lung Ventilation on PaO_2, $PaCO_2$, Peak Inspiratory Pressure, Heart Rate, and Mean Arterial Pressure

	One-lung ventilation	Alveolar recruitment strategy and PEEP during 1-lung ventilation
PaO_2 (mmHg)	224 ± 75	278 ± 67
$PaCO_2$ (mmHg)	41.1 ± 2.3	43.7± 2.6
Peak inspiratory pressure (cmH_2O)	28.7 ± 3.6	29.5 ± 2.7
Heart rate (beats/min)	115 ± 10.5	116 ± 6.5
Mean arterial pressure (mmHg)	65.0 ± 5.3	62.2 ± 3.8

Abbreviations: PaO_2: arterial oxygen partial pressure; $PaCO_2$: arterial blood carbon dioxide tension; PEEP: positive end-expiratory pressure.

The Fogarty occlusion embolectomy catheter has been described as a bronchial blockade to achieve lung isolation,[10] but it also has several disadvantages.[14] The Fogarty catheter is a vascular device, and is not designed to be used as a bronchial blocker. Placement may be difficult as it does not have a guide-wire device, and there is no communication channel in the center; therefore, suction or oxygen insufflation is not possible. Although its stylet facilitates insertion into the bronchus, it cannot be coupled with a fiberoptic bronchoscope. Air leakage from the breathing circuit is a common problem, especially when the Fogarty tube is placed inside a single-lumen endotracheal tube.

In pediatric populations, placement of the single-lumen endobronchial tube is another alternative for lung separation. It is easier to insert and position a single-lumen endobronchial tube. Although a single-lumen tube for endobronchial intubation enables 1-lung ventilation and can avoid the risk of intraoperative dislodgment of a blocker, it cannot provide suctioning and inflation of the contralateral lung during 1-lung ventilation.

Video-assisted thoracoscopic debridement has emerged as an innovative and popular procedure for children with empyema, while 1-lung ventilation and alternative uses of 2-lung ventilation are needed during this surgery. Our surgical department began using VATS for advanced-stage empyema of pleura

debridement in pediatric populations in 1995.[15] Evacuation of necrotic lung debris and peels was performed without significantly increasing morbidity. In this study, we sought a quick and reliable technique for 1-lung ventilation, using an FOB to accomplish selective WEB with a single-lumen endotracheal tube. We have successfully used an Arndt WEB to alternatively provide 1-lung and 2-lung ventilation during thoracoscopic procedures. The Arndt WEB is a bronchial blocker with a central lumen through which a wire with a looped end can be passed. The loop on the distal end is placed over the FOB as a guide to facilitate bronchial placement of the balloon-tipped bronchial blocker. Since a balloon-tipped catheter is inserted into the airway, there is always the possibility of balloon herniation in the trachea or overinflation and damage to the airway. The balloon device should always be inflated under direct vision to ensure that the correct volume of air is used. An advantage of the Arndt device is the airway adaptor that contains ports for an anesthesia circuit, the bronchoscope, the bronchial blocker as well as an attachment for the endotracheal tube. This special bronchoscopic port was designed to overcome many of the pitfalls of current endobronchial blocker technology. Ventilation is easily maintained during placement of the blocker. Removal of the wire following placement provides a central channel which allows some degree of suctioning through the channel to deflate the operative lung and improve surgical visualization. The bronchial blocker port has a self-sealing diaphragm that can be tightened down around the bronchial blocker to hold it in place, thereby preventing movement of the blocker and its potential dislodgement from the desired site. The bronchial blocker has a high-volume, low-pressure cuff with either an elliptical or spherical shape. By using the spherical cuff on the right bronchus, complete blockade can easily be achieved without proper inclusion of the right upper bronchus. One unsuccessful placement attempt was found in our study for left-sided VATS due to the very sharp angle between the left bronchus and the trachea. There was no hemodynamic deterioration or desaturation noted during 1-lung ventilation in this study. The alveolar recruitment strategy we applied to the dependent lung augmented PaO_2 values during 1-lung ventilation. Recruiting atelectatic zones of the dependent lung and applying sufficient levels of PEEP may attenuate the decrease in PaO_2 during 1-lung ventilation. Continued perfusion of the non-ventilated lung will result in a gross shunt effect associated with hypoxemia,[16] and the hypoxemia may be decreased by active hypoxic pulmonary vasoconstriction which results in a gradual redistribution of pulmonary blood flow away from the hypoxic collapsed lung into the ventilated lung.[17] In our study, we used a high inspiration oxygen concentration (F_iO_2 of 1.0), therefore it was of little value in minimizing arterial hypoxemia secondary to 1-lung ventilation during VATS. Because the Arndt blocker requires a single-lumen endotracheal tube, it maximizes the cross-sectional diameter, and eliminates the need for tube exchange if mechanical ventilation is contemplated in the postoperative period. Although our successful rate of using this tool was high and no complications were noted, Prabhu et al.[18] encountered difficulties in removing the deflated blocker catheter, which resulted in shearing of the balloon from the catheter. The possibility of other complications should not be neglected.

In summary, the Arndt wire-guided endobronchial blocker system offers a new tool to achieve 1-lung ventilation. The most important aspect of this system is its impact on the inner diameter across the sectional area of a conventional endotracheal tube. It offers the clinician alternatives for managing 1-lung ventilation during VATS for the treatment of lung empyema in smaller children. This method seemed to be more versatile, easy, practical and safe.

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在小兒蓄膿症胸腔內視鏡手術中使用新型Arndt支氣管阻斷器來進行單肺換氣呼吸麻醉

何綺月 陳俊宇 楊敏文 劉宏濱

背 景：經由視訊輔助內視鏡技術來處理小兒蓄膿症的這種顯微心臟手術，在兒童胸腔外科領域已經獲得廣泛的注意與重視。在此手術中單肺及雙肺的通氣切換有時候是必須的，本實驗是探討使用一個新型 Arndt 支氣管阻斷器來進行切換單肺及雙肺通氣的功能及功效。

方 法：共有18位小兒病人皆接受胸腔內視鏡手術來清除蓄膿症。我們使用一個支氣管阻斷器來完成手術中切換單肺及雙肺通氣的功能。

結 果：單肺的通氣當中在心跳、血壓都正常、血中含氧量都沒有明顯的降低。只有一例無法完成有效的單肺通氣。所有病人都得到足夠的通氣與抽氣。

結 論：在完整及完善的麻醉下，使用胸腔內視鏡手術中來處理小兒蓄膿症可以說是安全的。在手術中使用一個支氣管阻斷器來進行切換單肺及雙肺通氣是可行以及簡單的。

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關鍵字：單肺換氣呼吸，新型Arndt支氣管阻斷器，視訊輔助內視鏡技術。

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