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ORIGINAL ARTICLE

One-lung ventilation in infants and small children: blood gas values

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Abstract
Purpose We investigated one-lung ventilation (OLV) in pediatric patients under 10 kg. The feasibility of OLV using either Arndt endobronchial blocker (AEB) or mainstem intubation technique is analyzed. Arterial blood gases (ABG) monitored throughout the procedures are presented.
Methods Following IRB approval, a retrospective chart review was conducted on 9 patients $\leq$6 months of age and 2 patients $\geq$12 months of age undergoing lung resections or aortic coarctations. For right thoracotomy, a conventional, cuffed, endotracheal tube (ETT) was inserted and guided into the left mainstem bronchus with a bronchoscope and the left lung was ventilated. For left thoracotomy, an AEB was inserted into the trachea 2 cm past the vocal cords and an ETT was placed through the cords adjacent to the blockers (extraluminal). A bronchoscope was then inserted through the ETT to visualize and manipulate the blocker into the left mainstem bronchus. The blocker cuff was inflated slowly under direct vision while the ETT continued to ventilate the right, dependent lung. ABG values were collected intraoperatively in all cases.
Results One-lung ventilation could be accomplished within 15 min in all cases, and lung isolation was successful in all patients. All patients were extubated within 12 h of surgery and had an uneventful recovery. ABG values revealed modest arterial acidosis and hypercarbia and mild acute ventilatory insufficiency.
Conclusion The use of extraluminal AEB or mainstem intubation for OLV can be successfully completed in infants weighing less than 10 kg. OLV may induce acute respiratory pathology; therefore we recommend routine intraoperative ABG monitoring for pediatric patients.

Keywords Lung separation in infants · Bronchial blocker insertion · One-lung ventilation in infants

Introduction

The expanding role of thoracoscopy and video-assisted thoracoscopic surgery (VATS), and other thoracic operations, in the pediatric population requires one-lung ventilation (OLV). OLV provides improved exposure of the surgical field, and possibly a diversion of ventilation from the damaged airway or lung. On the other hand, it requires manipulation of the airways, along with significant physiological changes and potential hypoxemia. The complexity of the challenge of OLV increases with pediatric patients because of the rarity of this procedure, decreased airway size, and limited techniques available. Options for lung isolation options are limited in infants because endobronchial and Univent tubes are too large for smaller children. Various techniques for the use of Arndt endobronchial blockers (AEB) in children have been implemented with success.

Based upon the preoperative diagnoses of cardiopulmonary pathology in most patients requiring OLV, arterial blood gas (ABG) values are warranted to assess ventilation-to-perfusion (V/Q) mismatch and unrecognized, preexisting increases in the arterial CO_2-to-end-tidal CO_2

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gradient ($PaCO_2$–$ETCO_2$). These phenomena have been reported in children with prematurity, congenital heart and vascular abnormalities, and obstructive pulmonary disease resulting in increased physiological dead space (V_{DS}) [1].

We report 9 cases in which 5 French (5 Fr.) AEB was used to achieve OLV for left thoractomies and 2 cases in which bronchial advancement of the endotracheal tube (ETT) was utilized for right thoractomies. Although multiple studies in the past have already reported the use of AEB for OLV in the pediatric population, very few have reported on infants less than 10 kg in weight and none present ABG values.

Methods

This is a retrospective chart review (July 2009–Dec 2010) of 9 infants and 2 young children up to 10 kg requiring OLV. The chart review was approved by the Institutional Review Board of Nationwide Children Hospital, Columbus, OH. Patients were separated into three groups based on age and weight to enhance data interpretation (Table 1).

For right thoracotomy, a conventional, half-size smaller (than required for the age), cuffed (one patient was intubated with a 2.5-mm uncuffed ETT) ETT was inserted, then guided into the left mainstem bronchus with the 2.2-mm fiberoptic bronchoscope (FOB) (LFP, Olympus, Center Valley, PA, USA) (Fig. 1a). The cuffs were left uninflated unless there was a significant air leak. All ETTs utilized were Mallinckrodt (Covidien, Mansfield, MA, USA).

For left thoracotomy, the smallest 5 Fr. AEB (Cook Medical, Bloomington, IN, USA) was first inserted into the trachea 2 cm past the vocal cords, and a half-size smaller, cuffed, ETT was placed through the cords adjacent to the extraluminal blocker. The 2.2-mm LFP bronchoscope was then inserted through the ETT to visualize and manipulate the blocker into the left mainstem bronchus. The blocker cuff was inflated slowly under direct vision while the tracheal tube continued to ventilate the right, dependent lung (Fig. 1b). All procedures were completed after the initial intubation, and all additional maneuvers occurred while the patient was kept in the lateral position.

Standard ASA monitors were used. Anesthesia was maintained with sevoflurane in oxygen-enriched air. Small boluses of IV narcotic analgesics were utilized during the anesthetics. End-tidal CO_2 was measured with a standard Datascope monitor (AKW Medical, San Diego, CA, USA). Usual ventilator settings were pressure control, 20–24/4 cmH_2O; rate, 20–24 per min; with a FiO_2 from 0.5 to 1.0. All patients received dexamethasone 0.2 mg/kg after airway manipulations. An ABG was drawn 15 min after turning to the lateral position, while ventilating the single down lung. If desaturation to 90 % occurred, lung isolation efforts were stopped and standard two-lung ventilation resumed temporarily. Along with ABG values, other data

Table 1 Patient characteristics, isolation technique, and arterial blood gas (ABG) measured during single-lung ventilation of dependent lung at least 15 min into separation

Demographics				Lung separation		Arterial blood gases and derived values						
Patient	Age	Weight (kg)	Cuffed ETT size	Isolation technique	Ventilated lung	pH	PO_2	FiO_2	PO_2/FiO_2	PCO_2	$ETCO_2$	PCO_2–$ETCO_2$
Group 1												
1	2DO	3	3	Blocker	Right	7.38	91	0.6	147	40	29	11
2	3DO	2.5	2.5[a]	Blocker	Right	7.21	78	1	78	58	23	35
3	4DO	2.8	3	Blocker	Right	7.38	303	1	303	36	21	15
4	4WO	2.8	3	Blocker	Right	7.27	96	1	96	49	22	27
5	6WO	4.1	3	Blocker	Right	7.3	232	1	232	52	26	26
6	8WO	4.3	3	Blocker	Right	7.3	91	0.6	163	51	29	22
Group 2												
7	4MO	7.9	3.5	Mainstem	Left	7.28	83	0.5	166	48	26	22
8	4MO	7.4	3.5	Blocker	Right	7.17	209	1	209	69	47	22
9	5MO	7.4	3.5	Blocker	Right	7.29	83	0.6	136	50	12	38
Group 3												
10	15MO	9.8	4	Mainstem	Left	7.28	194	1	194	47	26	21
11	20MO	9.9	4	Blocker	Right	7.22	103	1	103	53	39	14

Groups are separated based on their age and weight

DO days old, *WO* weeks old, *MO* months old, *ABG* arterial blood gas

[a] Uncuffed endotracheal tube (ETT)

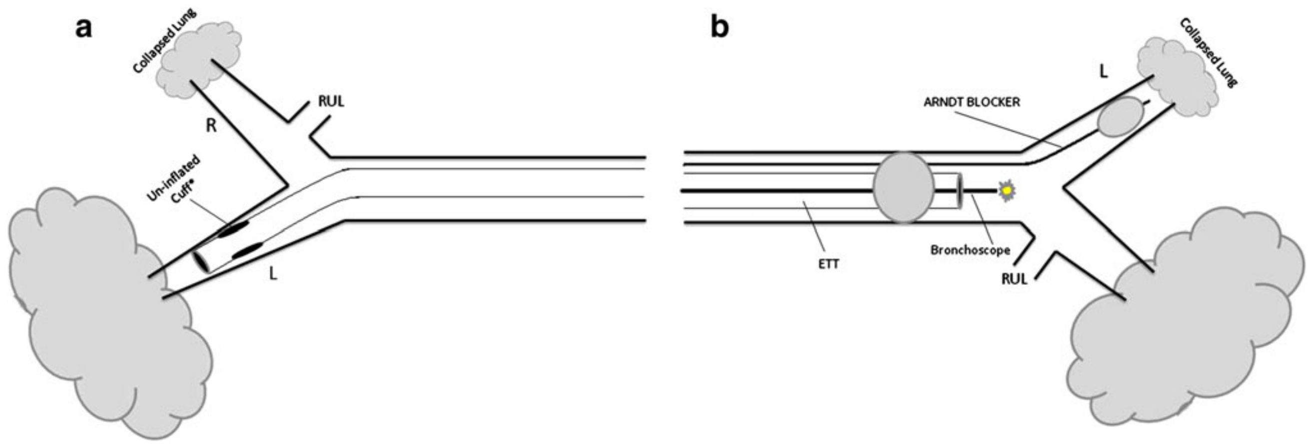

Fig. 1 **a** Right thoracotomy steps: place endotracheal tube (ETT) in the trachea; advance endotracheal tube into bronchial position. *ETT cuffs were left uninflated unless there was a leak around the ETT too large to allow effective positive pressure ventilation and/or reliable monitoring of ventilatory parameters became impossible. **b** Left thoracotomy steps: place Arndt blocker in the trachea; place endotracheal tube in the trachea; place bronchoscope into endotracheal tube; advance Arndt blocker under direct visualization via the bronchoscope and place in bronchial position; remove bronchoscope. *RUL* right upper lobe, *ETT* endotracheal tube

collected included age, weight, ETT size, lung isolation, and type of procedure.

Results

Lung isolation was rated good to excellent by the surgeon in all cases after initial separation; however, further blocker manipulation was required after positioning in five patients. No patients developed postoperative croup. All patients were successfully extubated within 12 h of surgery and had an uneventful recovery.

The procedures included seven lung resections for segmentectomies or bullae and four aortic coarctations repairs. Lung isolation was achieved in all patients who underwent left thoracotomy from 2 days to 8 weeks of age with the use of AEB.

Blood gas values

Table 1 describes arterial blood gases of the 11 infants undergoing thoracotomy who were included within this series.

The smallest group of patients, group 1, had an average weight of 3.2 kg. pH values revealed respiratory acidosis in four of the six patients and ranged from 7.21 to 7.38. Despite normal PO_2 (range, 91–303 mmHg) and FiO_2 (range, 0.6–1.0) values, PO_2/FiO_2 values indicate acute respiratory distress syndrome (ARDS) in four patients (range, 78–303). There were also four patients who were hypercarbic as determined from PCO_2 values (range, 36–58 mmHg). $ETCO_2$ values were between 21 and 29 mmHg, and PCO_2–$ETCO_2$ values (range, 11–35 mmHg) revealed that in all six patients there was a serious increase in physiological dead space.

In group 2, mainstem intubation was utilized in one patient and AEB was also utilized in two patients aged 4–5 months with an average weight of 7.6 kg. Again, pH values (range, 7.17–7.29) and PCO_2 values (range, 48–69 mmHg) revealed respiratory acidosis and hypercarbia in all three patients. PO_2 values ranged from 83 to 209 mmHg, FiO_2 ranged from 0.6 to 1.0, and $ETCO_2$ ranged from 12 to 46 mmHg. Two of the patients also met criteria for ARDS (PO_2/FiO_2, 166 and 136), and the third patient was close to this diagnosis (209 mmHg). All three patients had PCO_2–$ETCO_2$ (22–38 mmHg) values that also suggested increases in physiological dead space.

In the third group, two patients, aged 15 and 20 months, underwent lung isolation via mainstem intubation and AEB, respectively. Similar to the first two groups, both patients had respiratory acidosis (pH 7.28 and 7.22), ARDS (PO_2/FiO_2, 194 and 102), hypercarbia (PCO_2, 47 and 53 mmHg), and increased physiological dead space (PCO_2–$ETCO_2$, 21 and 14).

Discussion

Achieving OLV in the pediatric population has posed a unique challenge to anesthesiologists for many years. A review of the past literature shows various techniques and methods, yet no gold standard has ever been attained.

Our study presents exclusively pediatric patients weighing less than 10 kg and documents ABG data during single-lung ventilation. We describe the use of a single-lumen ETT advanced inside the left mainstem bronchus as the preferred method for patients undergoing right thoracotomy and the use of AEB advanced to the left mainstem bronchus for those patients undergoing left thoracotomy.

Use of an AEB versus direct mainstem occlusion is entirely dependent upon the operation being performed. The right bronchus is usually avoided for isolation because the right upper lobe bronchus is proximal and variable in location, making it difficult to successfully position the ETT or blocker. Therefore, as already mentioned, we recommend the use of a left mainstem intubation for single-lung ventilation for an operation requiring a right thoracotomy.

For left thoracotomy; we found that the most efficient blocker placement method was to place the blocker distally into the left bronchus with the patient supine and then, with bronchoscopy guidance, to adjust the position of the blocker after turning the child to the lateral position.

Our ABG values reveal oxygenation was usually adequate, but conventional ventilator settings frequently resulted in hypercarbia that was not reliably detected with capnography. Therefore, arterial line placement for blood gas analysis is recommended. Gas exchange may not always be adequate because of a falsely low reading by the capnograph. Additionally, blockers can become displaced; thus, careful monitoring is essential.

Hammer and colleagues have published extensively on OLV in the pediatric population. They have achieved OLV through multiple methods from single-lumen ETT, uninvent tube, double-lumen ETT, to Fogarty embolectomy catheter used as a bronchial blocker, and AEBs [2, 3]. Tobias [4] and Levine and Slinger [5] also describe endobronchial blocker insertion to achieve OLV in this population.

Yun and colleagues [6] describe a method of achieving OLV through the use of a 5 Fr. pediatric wire-guided endobronchial blocker positioned through a 7.0-mm cuffed ETT. Using this technique they successfully achieved OLV in a 45-kg, 14-year-old patient undergoing an aortic coarctation repair and concluded that, because of the small diameter of the endobronchial blocker, this device can be used in a small ETT without sacrificing the inner-diameter cross-sectional area.

Use and colleagues [7] describe the use of a 4 Fr. Fogarty catheter with a hollow center (Fogarty Thru-Lumen Embolectomy; Baxter) as a bronchial blocker for OLV. They described advancing the 4 Fr. Fogarty catheter to the left mainstem bronchus through a 5.5-mm ETT under direct view with a fiberscope. They describe this technique in a 6-year-old child with left pulmonary sequestration undergoing video-assisted thoracoscopic left lower lobectomy. Again, despite its success, this technique also fell short because of the large size of the Fogarty catheter and ETT. We prefer AEB over the Fogarty catheter for OLV, especially when placing extraluminally, because the stiffer high-pressure cuff may cause more bronchial damage.

Lew [8] describes selective bronchial intubation using a single-lumen tube in achieving OLV. He describes a case where this technique was used in achieving OLV for a 10-kg, 2-year 2-month-old patient requiring right thoracotomy. Lew does state complications with severe carbon dioxide (CO_2) retention. Lew blames inadequate tidal volume generated for the child, as the left lung expansion was extremely restricted. As described next, we used a similar method to achieve OLV in patients undergoing right thoracotomy.

Schmidt and colleagues [9] describe the use of a 65-cm double-lumen fiberoptic wire-guided endobronchial blocker (FWEB) in a 3,000-g, 40-day-old infant with congenital emphysema requiring left upper pulmonary lobe resection. They intubated the patient nasally via an uncuffed 4.0-mm (inner diameter) ETT; subsequently, the FWEB was coaxially guided into the left mainstem bronchus using a 2.0-mm fiberscope. As described below this technique differs from ours in that both the FWEB and fiberscope were placed through the ETT; in our study, the blocker remained outside the ETT throughout the operation.

The various techniques for lung isolation utilizing AEB have been described in great detail by Stephenson and Seefelder [10] in their experience of 26 patients. They describe in stepwise fashion the sequence of inserting a 5 Fr. AEB extraluminally, while guiding its positioning with intraluminal FOB. They were successfully in separating lung ventilation in 23 (88.5 %) of their patients: 6 had a body weight greater than 10 kg. Similarly, the AEB was also described for successful lung separation in a group of pediatric patients by Wald et al. [11]; however, half the patient population was older than 5 years of age.

We have reaffirmed the effective practice of extraluminal placement of a 5 Fr. AEB into the mainstem bronchus and the use of mainstem intubation for OLV in infants as young as 2 days and as small as 2.5 kg. OLV can be safely performed in infants when Arndt blockers, pediatric bronchoscopes, and expertise with their use are available. Our blood gas evaluation suggests that without intraoperative ABG values, it may be difficult to accurately interpret $ETCO_2$ obtained from small tidal volumes. In conclusion, despite adequate oxygenation, the drastic physiological changes involved with OLV significantly affect the respiratory function of infants and young children.

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