**Title:** Anesthetic management of thoracoscopic resection of lung lesions in small children.

**Abbreviated title**: Anesthesia for thoracoscopic surgery in small children.

**Article category**: Research report.

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**What is already known**

- Various techniques for one-lung ventilation in children have been described but the optimal technique is yet to be established.
- Remifentanil infusion has been used successfully in young children for abdominal surgery but its use in video-assisted thoracoscopic surgery in small children has not been described.

**What new information this study adds**

- This article reports the successful placement of an extraluminal parallel blocker to achieve one-lung ventilation in young children undergoing thoracoscopic excision of congenital pulmonary lesions.
- Remifentanil infusion is an effective and highly titratable ~~analgesics~~ analgesic technique in infants and small children undergoing video-assisted thoracoscopic surgery.

**Summary**

**Background:** Video-assisted thoracoscopic surgery has dramatically increased over the last decade because of both medical and cosmetic benefits. Anesthesia for video-assisted thoracoscopic surgery in small children is more challenging compared to adults due to the considerable problems posed by small airway dimensions and ventilation. The optimal technique for one lung ventilation has yet to be established and the use of remifentanil infusion in this setting is not well described.

**Aims:** This study investigated the use of extraluminal bronchial blocker placement for one lung ventilation and the effect of infusion of remifentanil in infants and small children undergoing video-assisted thoracoscopic surgery.

**Methods**: We retrospectively reviewed the technique of one-lung ventilation and the hemodynamic effects of remifentanil infusion in thirty-one small children during elective video-assisted thoracoscopic surgery for congenital lung lesions under anesthesia with sevoflurane or isoflurane, oxygen and air. Patients' heart rate, blood pressure and end-tidal carbon dioxide at baseline (after induction of anesthesia), immediately after one lung ventilation, during carbon dioxide insufflation, and at the end of one-lung ventilation were extracted from the database and analyzed. The use of vasopressors or dexmedetomidine was also recorded and analyzed.

**Results**: Extraluminal placement of a bronchial blocker alongside the tracheal tube was successfully performed in 96.7% of cases (29 patients) without any serious complications or arterial oxygen desaturation. There was no significant rise in blood pressure or heart rate even with the rise of end-tidal carbon dioxide concentration during video assisted thoracoscopic surgery. In 58% of patients (18

patients), phenylephrine was administered to maintain the blood pressure within 20% of the baseline value. There was no significant change in the heart rate of all patients at each time point.

**Conclusions**: One-lung ventilation with an extraluminal parallel blocker was used effectively in this series of young children undergoing thoracoscopic excision of congenital pulmonary lesions. Remifentanil infusion attenuated surgical stress effectively in infants and small children undergoing video-assisted thoracoscopic surgery.

**Keywords:**

Video-assisted thoracoscopic surgery, congenital lung lesions, small children, one- lung ventilation, bronchial blocker, remifentanil.

**Introduction**

In recent years, the diagnosis of congenital lung malformations in infants and small children has increased due to improvement in routine antenatal ultrasound and postnatal imaging.[1,2] The most common lesions are congenital pulmonary airway malformation (CPAM; previously known as congenital cystic adenomatoid malformation) and pulmonary sequestration. In these malformations, despite the lack of symptoms, patients are at risk of recurrent chest infections and, if left untreated, malignant transformation can occur.[3] For these reasons, congenital lung lesions were traditionally resected electively by pulmonary lobectomy via a posterolateral thoracotomy incision. However, over the last decade, technology for video-assisted thoracoscopic resection for congenital lung malformations has dramatically improved and has now become the standard technique. The advantages of video-assisted thoracoscopic surgery compared with open thoracotomy include smaller chest incision, reduced postoperative pain, more rapid recovery and shorter hospital stay.[4,5] Moreover, long term musculoskeletal complications associated with posterolateral thoracotomy, such as asymmetric chest wall, scoliosis and winged scapula, are avoided.[6]

Video-assisted thoracoscopic procedures in children require one-lung ventilation to facilitate clear visualization of thoracic contents and reduce lung injury from the use of retractors.[7] Methods that have been used for lung isolation in children include single-lumen endobronchial tubes, double-lumen tracheal tubes, Univent™ tracheal tubes (Fuji Systems Corporation, Tokyo, Japan) and balloon-tipped endobronchial blockers. Nevertheless, because of the considerable constraints imposed by small airway dimensions, a clinical “gold standard” for one- lung ventilation has not yet been established.[8] Furthermore, lung isolation and intraoperative remifentanil (an ultra-short acting opioid) infusion have

mostly been described only in older children. The purpose of this report is to describe our anesthetic experience with video-assisted thoracoscopic resection of congenital lung malformations in small children of 3 months to 5 years of age with special emphasis on the one- lung ventilation technique and intraoperative use of remifentanil.

**Materials and Methods**

With approval from our local institutional review board, the database and records of paediatric patients who had video-assisted thoracoscopic resection for congenital pulmonary lesions with one lung ventilation from 2007 to 2013 in Queen Mary Hospital, Hong Kong, were retrieved from the hospital's electronic Clinical Management System and Anesthetic Information System (CompuRecord™, Philips Medical Systems, Eindhoven, Netherlands). Exclusion criteria were patients less than 3 months old, ASA 4 and above and emergency surgery. In our institution, elective resection of asymptomatic pulmonary lesions is done at the age of at least 3 months.[9] Demographic data and method of one lung ventilation and anesthetic technique were documented. Hemodynamic and respiratory variables were recorded at T1 baseline (after induction of anesthesia); T2 immediately after one- lung ventilation; T3 during carbon dioxide insufflation and T4 at the end of one- lung ventilation. The administration of any vasoactive agent or dexmedetomidine was also extracted from the database and analyzed.

*Anesthetic Management*

Video-assisted thoracoscopic surgery was performed under general anesthesia in lateral decubitus position. Standard monitoring includes electrocardiogram, pulse oximetry (SpO2) and non-invasive blood pressure plus invasive arterial blood pressure using IntelliVue MP90 (Philips Healthcare, Eindhoven, Netherlands). Anesthetic induction was either inhalational with sevoflurane or

intravenously with propofol. Atracurium was given to facilitate endotracheal intubation. A standard uncuffed endotracheal tube ranging from 3.0 to 5.0 mm internal diameter (based on predicted age formula) was first inserted into either the left or right main bronchus of each patient depending on the site of surgery. Correct tube placement was confirmed by clinical auscultation. This endotracheal tube was used to position the respective 3, 4 or 5 F bronchial blocker.

For one lung isolation in children younger than 6 years of age, a balloon-tipped bronchial blocker: either a Fogarty® embolectomy catheter (Edwards Lifesciences Corp, Singapore) or an Arndt® endobronchial blocker, (Cook Medical, IN, USA) was selected. When the blocker was in the selected bronchus, the first endotracheal tube was then pulled out to the proximal end of the bronchial blocker, leaving the bronchial blocker in situ. Subsequently, another endotracheal tube was inserted into the trachea and secured. A Microcuff® tracheal tube (Kimberly-Clark, Roswell, GA, USA) was selected for endotracheal intubation, except in the early period of the case series where we used an uncuffed standard tube in nine patients. A 2.2 or 2.8 mm flexible fiberoptic bronchoscope (depending on the size of the endotracheal tube used) was advanced to confirm the correct position of the endotracheal and bronchial tubes, as well as to visualize the volumes of air needed to produce an adequate seal following bronchial balloon inflation. The bronchoscope was then removed, and the bronchial blocker was securely taped to the face. After lateral decubitus positioning, further auscultation and fiberoptic visualization reconfirmed the proper placement of the bronchial blocker. Maintenance of anesthesia was with sevoflurane (1.5-2.5%) or isoflurane (0.7-1.4%), oxygen and air. For each patient, remifentanil was used for intraoperative analgesia by continuous infusion. Average remifentanil infusion rate was calculated as total remifentanil infusion dose/weight/duration of remifentanil infusion. Intravenous dexmedetomidine was given routinely (after it became available in our institution) as a slow bolus or infusion for its anesthetic sparing[10], analgesic[11], and possible neuroprotective effects.[12]

Dexmedetomidine also reduces emergence delirium in young children.[13]

Pressure controlled mechanical ventilation was provided using the General Electric Aestiva/5™ (DatexOhmeda, Inc, Madison, WI, USA) anesthesia machine. Single lung ventilation was commenced immediately after inflation of the bronchial blocker under fiberoptic control. All patients received 100% inspiratory oxygen concentration to facilitate absorption atelectasis of the blocked lung. For patients in whom the blind ended Fogarty® embolectomy catheter was inserted, a short period of apnea and suctioning preceding balloon inflation; insufflation of carbon dioxide into the hemithorax and manual compression of the lung by surgeon prior to balloon inflation at the beginning of surgery accelerated lung deflation. When using the Arndt® endobronchial blocker, the lung could be emptied via the working canal when the lasso was removed. Over time, the inspired oxygen concentration was gradually decreased, titrating to maintain a $SpO_2$ > 95%. The ventilator settings were adjusted during the video-assisted thoracoscopic procedure with smaller tidal volumes and increased respiratory rates. The peak inspiratory pressure was limited to <30cm$H_2O$, allowing some degree of permissive hypercapnia.

All patients received a bolus of intravenous morphine and paracetamol (except in the early period of the case series when the intravenous formulation was unavailable, per rectum was used) intra-operatively and skin wound infiltration with 0.25% levobupivacaine towards the end of the surgical procedure. An intercostal nerve block was performed if the procedure was converted to open thoracotomy.

**Results**

Of the 60 cases that were initially identified, 26 did not meet the inclusion criteria and 3 were excluded because one lung ventilation technique was deemed not necessary by the surgeon, resulting in 31 cases studied. (Fig 1) Demographic data are shown in Table 1. Seventeen patients were infants, 12 were aged between 13-24 months and only two patients aged more than 24 months at the time of surgery; of which the oldest patient in this group was operated on for recurrent congenital pulmonary airway malformation. Thirty patients were diagnosed antenatally, between 20 and 37 weeks by ultrasonography and were asymptomatic after birth. Only one patient with associated multiple congenital abnormalities was diagnosed in the postnatal period. One patient presented at four months of age with respiratory symptoms. Postnatal chest X-ray did not show any abnormal lesion in 7 patients; however, thoracic computed tomography showed the prenatally detected lung lesions in all.

Single lung isolation was required during video-assisted thoracoscopic surgery in 31 patients (Table 2). The extraluminal parallel placement technique of bronchial blocker to tracheal tube was performed in 29 patients. Size of the Fogarty® catheter and Arndt® blockers are reported in table 2. In our series, 29 of the 31 patients (93.5%) had successful blocker placement and complete lung isolation. A Fogarty® catheter was used in seventeen patients and an Arndt® endobronchial blocker in the rest.

Eighteen bronchial blockers were placed in the right main bronchus and twelve in the left. Left main bronchus bronchial blocker placement failed in a 20-month baby girl, the first patient of this case series, in whom the nature and size of the bronchial blocker used was not recorded. Intraoperative flexible fiberoptic bronchoscopy was used to identify technical problems and to assist in their management. In a 3-year-old girl (patient 21) with congenital pulmonary airway malformation of the left lower lobe, leakage of the 5F Arndt® blocker's balloon led to re-expansion of the left lung during

surgical resection. The leaking Arndt® blocker was exchanged for a Fogarty® catheter under bronchoscopic guidance. However, after about half an hour on one- lung ventilation, the Fogarty® catheter slipped out. The endotracheal tube was pushed into the right main bronchus under fiberoptic bronchoscope visualization to re-establish one- lung ventilation. There were no serious adverse events during the incident. There was also no episode of significant desaturation with apneic ventilation during bronchial blocker placement and flexible bronchoscopy. In one patient, it was not possible to achieve complete one lung isolation because of a very high origin of the right upper-lobe bronchus. However, it did not create any significant problems intraoperatively.

Apart from the three patients mentioned above, there were no other immediate or delayed complications from bronchial blocker placement. In four patients, surgeons converted the thoracoscopic procedure to an open thoracotomy for surgical reasons. These included bleeding, severe adhesions and an exceptionally large lesion with difficult resection. All patients, except one (patient 14) who had underlying cyanotic congenital heart disease, tolerated the thoracoscopic insufflation of carbon dioxide to a pressure of 4-5 mmHg at basal flow of 1L.min-1. The significant oxygen desaturations contributed to the decision to convert to open thoracotomy in this patient. The maximum end-tidal carbon dioxide recorded in this series of patients was 9.5kPa. Hemodynamic and respiratory data at T1 represent maintenance of anesthesia without the influence of surgical stimulation (baseline values). Data sets at T2 were recorded immediately after one- lung ventilation, T3 shortly after carbon dioxide insufflation and T4 at the end of one- lung ventilation. (Table 3) There was an expected rise in end-tidal carbon dioxide with carbon dioxide insufflation (Table 3). The blood pressures (systolic, mean and diastolic) were relatively constant at these four-time points. Heart rates showed a similar pattern throughout these periods. (Table 3).

The average remifentanil infusion rate ranged from 0.08 - 0.30 mcg.kg$^{-1}$.min$^{-1}$. Among these 31 patients, 18 (58%) were given the phenylephrine as bolus or as infusion. Of the 23 patients who were also given intravenous dexmedetomidine, 21 received a bolus dose of 0.3-0.9 mcg.kg$^{-1}$. In 2 patients, dexmedetomidine was administered as an infusion throughout surgery with total dose ranging from 1.25 -1.9 mcg.kg$^{-1}$. Among these patients, 14 (60.5%) received phenylephrine. Out of the eight remaining patients who were not given dexmedetomidine, four (50%) received phenylephrine.

We could not find any association between the dose of drugs, age, side of operation, intrathoracic inflation pressure, or peak inspiratory pressure and the administration of vasopressor in this cohort of patients. The number of cases is, however, relatively small and very likely to be underpowered to adequately detect or explain such an association.

Twenty-six patients were extubated at the end of surgery and were managed in the pediatric intensive care unit. Among five patients whose lungs were ventilated postoperatively, two occurred early in the case series. One patient had difficult surgery for congenital emphysema with a long duration of anesthesia (about 8 hours) and another two had intra-operative bleeding which necessitated conversion to open thoracotomy. Mean pediatric intensive care unit stay was 1.7 days, and mean hospital stay was 3.9 days.

**Discussion**

Antenatal diagnosis of congenital pulmonary malformations is increasing and leads to presentation for

resection in early infancy. Video-assisted thoracoscopic surgery is now the technique of choice in both adult and pediatric thoracic surgery because of smaller chest incisions, reduced postoperative pain and more rapid recovery compared with thoracotomy.[5,6,14] This change in surgical technique has influenced anesthetic management. Although video-assisted thoracoscopic surgery can be performed by creating a capnothorax, via insufflation of carbon dioxide into the pleural cavity, one-lung ventilation of the nonoperative lung optimizes surgical exposure.[15]

There are several techniques for one-lung ventilation in pediatric patients. Selective contralateral mainstem bronchus intubation for one-lung ventilation has been described.[16] For older children, double-lumen tube and UninventTM tube® (Fuji Systems Corporation, Tokyo, Japan) are available for lung isolation. However, both double-lumen tubes and UniventTM tubes are unsuitable in infants and small children because of their large outer diameter.[17] Therefore, other techniques are often required. A specially designed double-lumen tube (Marraro)® for neonates and infants has been used successfully,[18] but it is not widely available. Hence, endobronchial intubation with a balloon-tipped bronchial blocker such as the Arndt® endobronchial blocker or Fogarty® embolectomy catheter is the technique often used to achieve one-lung ventilation in this age group of children.

In older children, the Arndt® endobronchial blocker is inserted through the endotracheal tube (endoluminal) and alongside the fiberoptic bronchoscope. After advancing the bronchoscope into the desired bronchus, the blocker is then threaded into location by a guide loop. However, with this endoluminal method, the smallest 5F Arndt® endobronchial blocker requires at least a 4.5mm ID endotracheal tube which limits the technique to patients 2 years and older.[19] An alternative method is needed to achieve one-lung ventilation in infants with smaller endotracheal tubes. For extraluminal

placement, the blocker is placed alongside the endotracheal tube and different methods of extraluminal placement of the blocker have been reported. In our institution, because the vast majority of the patients were less than 24-months old, parallel extraluminal blocker placement using 3 or 4F Fogarty® embolectomy catheter (5F Arndt® blocker in bigger children) was the technique of choice. We achieved this by temporary intubation of the desired main bronchus with an uncuffed tracheal tube to guide the blocker placement, after which the endotracheal tube was withdrawn. A second tracheal tube, Microcuff® (Kimberly-Clark, Roswell, GA, USA), was then inserted parallel to the blocker into the trachea. Flexible fiberoptic bronchoscopy confirmed optimal blocker placement and cuff inflation whilst the patient was ventilated using an adapter with a side port for ventilation. Due to familiarity with this technique, there was no significant episode of desaturation even with a period of apnea during the placement procedure. Fluoroscopic guidance of the extraluminal blocker has been reported but requires radiation exposure.[20]

More recently, we have used the 4F Python® embolectomy catheter [Applied Medical Resources Corporation, California, USA] in place of the Fogarty® catheter. This embolectomy catheter is easier to manipulate directly into the mainstem bronchus under fiberoptic guidance, negating the need to use an endotracheal tube as a conduit. However, in the occasional difficult anatomy, using an endotracheal tube as a conduit is still necessary.

Inflation of the bronchial blocker balloon to achieve an adequate seal is required for lung collapse and better operating conditions. This is done under fiberoptic guidance until the balloon reaches the bronchial wall with a variable amount of air needed depending on the patients' age and weight.[16] There is the potential risk of blocker balloon dislodgement into the trachea although in our series, this

only happened once. Direct fiberoptic visualization during balloon inflation as well as during manipulation is important to prevent injuries related to the balloon inside the small main bronchus, particularly pressure-induced mucosal trauma. Most of the bronchial blocker balloons have low-volume high–pressure properties. Over distension of the blocker balloon can damage or rupture the airway[21]or herniate into the carina with blockage of both bronchi.

The use of an ultrathin polyurethane Microcuff® endotracheal tube with an extraluminal blocker provides a sufficient seal to achieve adequate ventilation pressures and optimal gas exchange as well as a more precise capnograph trace, decreased consumption of inhalational anesthetic agents and less environmental pollution. The ability to provide effective ventilation is particularly beneficial during video-assisted thoracoscopic procedures where alterations in compliance and ventilation may result in the need to alter peak inflation pressures.[22]

During video-assisted thoracoscopic surgery, both one-lung ventilation and carbon dioxide insufflation are associated with an increased risk of hypercapnea and its consequences.[23] In our series, both the heart rate and blood pressures were fairly stable throughout the procedure. We routinely use remifentanil infusion at an average infusion rate of 0.08-0.30 $mcg.kg^{-1}.min^{-1}$. The pharmacodynamics effects of remifentanil according to age have been reported. Michel F et al showed that the heart rate and mean blood pressure did not vary in neonates and older children up to 2 years who underwent general anesthesia with remifentanil-sevoflurane for abdominal surgery. However, lower doses of remifentanil and lower concentrations of sevoflurane in neonates were used compared with the older children.[24] Remifentanil is highly titratable with a fast onset and short duration of action, allowing rapid recovery after surgery. This allows us to achieve high analgesic doses intraoperatively without the

need for postoperative ventilation.

In the 23 patients who were given dexmedetomidine, we did not find any association with bradycardia or hypotension during administration. This is probably related to the small dose administered. We cannot comment on potential beneficial effects such as anesthetic sparing, analgesia or emergence delirium with dexmedetomidine because of the small number of patients.

It is important to note that this is a retrospective observational study, wherein all the data collected were from the patients' records and the administration of remifentanil, inhalational agent, other analgesics and fluids were not controlled. Therefore, we cannot be certain that the dose adjustments directly link to the hemodynamic effects and confounding variables cannot be excluded. Future prospective, randomized controlled trials are required to further evaluate this effect.

One-lung ventilation with extraluminal parallel blocker placement can be used effectively in young children undergoing thoracoscopic excision of congenital pulmonary lesions. Remifentanil infusion for video-assisted thoracoscopic surgery was highly titratable and effective in infants and small children.

**Ethics Approval**

This study was approved by the local institutional review board at Queen Mary Hospital, Hong Kong.

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This study was carried out without funding.

**Conflict of interest**

The authors report no conflict of interest.

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**Table 1**: Demographic and surgical diagnosis of patients undergoing thoracoscopic resection of lung lesions

| | n (%) |
|---|---|
| Sex | |
| Male | 18 (58) |
| Female | 13 (42) |
| ASA physical status grade | |
| I | 8 (25.8) |
| II | 21 (67.7) |
| III | 2 (6.5) |
| Age (months) | |
| 3 – 12 | 17 (54.8) |
| 13 – 24 | 12 (38.7) |
| > 24 | 2 (6.5) |
| Body Weight (kg) | |
| < 10 | 21 (67.8) |
| 10-20 | 9 (29) |
| > 20 | 1 (3.2) |
| Diagnosis | |
| Congenital Pulmonary Airway Malformation | 22 (71) |
| Pulmonary Sequestration | 7 (22.6) |
| Lung Emphysema | 1 (3.2) |
| Benign Cystic Lesion | 1 (3.2) |

**Table 2** : Characteristics of 31 patients who underwent thoracoscopic resection with an one-lung ventilation technique. M, male; F, female; LLL, left lower lobe; LUL, left upper lobe; RLL, right lower lobe; RUL, right upper lobe; LMB, left main bronchus; RMB, right main bronchus; CPAM, congenital pulmonary airway malformation; PS, pulmonary sequestration.

| Patient | Sex | Age | Weight (kg) | Diagnosis | Converted to open | Endotracheal tube | Bronchial Blocker | Isolation side | Success |
|---|---|---|---|---|---|---|---|---|---|
| 1 | F | 20 months | 9.4 | LLL CPAM | No | 4.0 uncuffed | ~~? type and size~~not recorded | LMB | No |
| 2 | M | 4 months | 6.8 | LUL CPAM | No | 3.5 uncuffed | 5F Arndt | LMB | Yes |
| 3 | M | 7 months | 8.5 | LLL PS | No | 4.0 uncuffed | 5F Arndt | LMB | Yes |
| 4 | M | 4 months | 6.4 | RLL CPAM | Yes, bleeding | 3.5 uncuffed | 5F Arndt | RMB | Yes |
| 5 | M | 13 months | 10 | LLL PS | No | 4.0 uncuffed | 4F Fogarty | LMB | Yes |
| 6 | M | 7 months | 8.9 | LLL CPAM | No | 4.0 uncuffed | 5F Arndt | LMB | Yes |
| 7 | M | 17 months | 10.8 | RLL CPAM | Yes, surgical difficulty | 4.5 microcuffed | 5F Arndt* intraluminal | RMB | Yes |
| 8 | M | 9 months | 9.4 | RLL PS | No | 3.5 microcuffed | 4F Fogarty | RMB | Yes |
| 9 | F | 7 months | 6.7 | LLL PS | No | 4.0 uncuffed | 3F Fogarty | LMB | Yes |
| 10 | M | 8 months | 8.2 | LLL PS | No | 4.0 uncuffed | 3F Fogarty | LMB | Yes |
| 11 | M | 19 months | 9.3 | RLL CPAM | No | 4.0 microcuffed | 4F Fogarty | RMB | Yes |
| 12 | M | 10 months | 9.7 | RLL CPAM | No | 4.0 microcuffed | 4F Fogarty | RMB | Yes |
| 13 | F | 18 months | 9.9 | RLL CPAM | No | 4.0 microcuffed | 5F Arndt | RMB | Yes |
| 14 | M | 13 months | 10.1 | RLL CPAM | Yes, oxygen desaturation | 3.5 microcuffed | 4F Fogarty | RMB | Yes |
| 15 | M | 8 months | 7.9 | LUL Congenital emphysema | No | 4.0 microcuffed | 4F Fogarty | LMB | Yes |
| 16 | M | 9 months | 10.2 | RLL CPAM | Yes, bleeding | 3.5 microcuffed | 4F Fogarty | RMB | Yes |
| 17 | F | 18 months | 9.6 | RLL CPAM | No | 3.5 microcuffed | 5F Arndt | RMB | Yes |
| 18 | F | 5 years | 23.9 | RLL CPAM (recurrent) | Yes, surgical difficulty | 5.0 microcuffed | 5F Arndt | RMB | Yes |
| 19 | F | 5 months | 4.3 | Cystic Lesion | No | 3.0 microcuffed | 4F Fogarty | RMB | Yes |
| 20 | F | 16 months | 10 | RUL CPAM | No | 3.5 microcuffed | 5F Arndt | RMB | Yes |
| 21 | F | 3 years | 13.3 | LLL CPAM | No | 4.5 microcuffed | 5F Arndt | LMB | Yes balloon leak |
| 22 | F | 12 months | 11.6 | RUL CPAM | No | 4.0 microcuffed | 4F Fogarty | RMB | Yes |
| 23 | F | 12 months | 9.6 | LLL CPAM | No | 3.5 microcuffed | 5F Arndt | LMB | Yes |
| 24 | M | 8 months | 7.7 | LLL CPAM | No | 3.5 microcuffed | 4F Fogarty | LMB | Yes |
| 25 | F | 19 months | 9.4 | LLL CPAM | No | 4.0 microcuffed | 4F Fogarty | LMB | Yes |
| 26 | M | 13 months | 11.1 | RLL CPAM | No | 3.5 microcuffed | 4F Fogarty | RMB | Yes |
| 27 | M | 16 months | 9.7 | RLL CPAM | No | 3.5 microcuffed | 5F Arndt | RMB | Yes |
| 28 | F | 11 months | 8.5 | RLL PS | No | 3.5 microcuffed | 4F Fogarty | RMB | Yes |
| 29 | M | 21 months | 10.7 | RLL CPAM | No | 4.0 microcuffed | 5F Arndt | RMB | Yes |
| 30 | M | 7 months | 7.9 | LLL PS | No | 3.5 microcuffed | 4F Fogarty | LMB | Yes |
| 31 | F | 6 months | 7.8 | LLL CPAM | No | 3.0 microcuffed | 4F Fogarty | LMB | Yes |

| **Table 3**: Physiological variables measured at different time points | | | | |
|---|---|---|---|---|
| | T1 | T2 | T3 | T4 |
| **Hemodynamic variables:** | | | | |
| Heart Rates (beats. $min^{-1}$) | 132 (125-140) | 128 (112-140) | 125 (120-135) | 128 (120-135) |
| SBP (mmHg) | 90 (84-98) | 84 (78-92) | 84 (78-84) | 85 (80-90) |
| MAP (mmHg) | 58 (56-62) | 60 (57-62) | 59 (54-64) | 58 (54-62) |
| DBP (mmHg) | 48 (44-50) | 46 (43-51) | 48 (42-52) | 45 (42-50) |
| **Respiratory variables:** | | | | |
| $ETCO_2$ (kPa) | 4.6 (3.8-4.6) | 5.0 (4.4-5.7) | 5.9 (5.2-6.8) | 5.3 (4.5-6.1) |

T1 baseline (after induction of anesthesia), T2 immediately after one-lung ventilation, T3 shortly after insufflation of carbon dioxide, T4 end of one-lung ventilation.
SBP, systolic blood pressure; MAP, mean arterial blood pressure; DBP, diastolic blood pressure.
Results are presented as median (interquartile range)

**Figure captions:**

**FIGURE 1.** Consort flow diagram following the recruitment of 31 patients for analysis.