Single-Lung Ventilation in Children: Techniques, Monitoring, and Side Effects

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14.1 Introduction

Thoracoscopy is increasingly being used for thoracic surgery in both adults and children. Improvements in technology and surgical skills are the main reasons for the dramatic increase in patients being referred for thoracoscopic surgery. As the age and weight of the patients being referred for surgery are declining, newborns and infants are frequently scheduled for thoracoscopic surgery. Deflation of the lung at the surgical site is extremely useful for adequate surgical exposure, especially in the case of pulmonary resection [1].

From an anesthesia point of view, the main obstacle is the performance of reliable single-lung ventilation (SLV) with deflation and immobility of the lung at the surgical site. Double-lumen endobronchial tubes, Univent tubes (Fuji Systems, Tokyo, Japan), and bronchial intubation are some of the techniques described for SLV [2–3]. Alternatively, conventional double-lung ventilation facilitates the collapse of the lung at the surgical site by insufflation of the CO_2 used for the thoracoscopic procedure [4]. These strategies, especially bronchial intubation and double-lung ventilation, cannot be considered as completely satisfactory and should be seen as surrogates of SLV, as described for adult patients. The commercial introduction of the Arndt 5 French (Fr) pediatric endobronchial blocker (COOK MEDICAL Inc., Bloomington, Illinois, USA) for SLV has proved to be a reliable option for SLV, even in children and small infants. The rest of this chapter describes the physiology of SLV in children, the pros and cons of the different devices used in SLV, and the currently available SLV techniques.

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14.2 Physiology of Single-Lung Ventilation

Ventilation is normally distributed preferentially toward the dependent regions of the lung, with a gradient of increasing ventilation from the nondependent (up) to the dependent lung segments (down). Because of gravitational forces, perfusion normally follows a similar distribution, with increased blood flow toward the dependent lung segments. Therefore, ventilation and perfusion are normally well balanced. During thoracic surgery, several factors interact to affect the ventilation/perfusion (V/Q) balance.

Compression of the dependent lung in the lateral decubitus position and SLV with collapse of the operative lung are both responsible for atelectasis. Hypoxic pulmonary vasoconstriction acts to divert blood flow away from underventilated lung regions, thereby minimizing any V/Q imbalance. However, the overall effect of the lateral decubitus position on the V/Q balance is different in infants compared to older children and adults.

In infants with unilateral lung disease, oxygenation is improved with the healthy lung "up". This physiological phenomenon differs significantly between adults and infants. The main reasons for this difference are the soft and easily compressed thoracic cage and a functional residual capacity closer to the residual volume, which make airway closure likely to occur in the dependent lung even during tidal breathing. Finally, the increased oxygen requirement and the small functional residual capacity predispose children to hypoxemia. All of these factors must be taken into account every time a child undergoes SLV for thoracic surgery.

14.3 Single-Lung Ventilation Techniques

14.3.1 Selective Endobronchial Intubation

This technique is performed by advancing the tracheal tube into one of the mainstem bronchi until breath sounds on the operative side disappear. This is a simple technique that does not require special equipment other than a fiberoptic scope. The main disadvantages are the inability to completely collapse and suction the operative lung, and the incomplete protection of the healthy lung from purulent material or blood originating from the operative side. Moreover, hypoxemia may occur due to obstruction of the upper lobe bronchus, especially when the short right mainstem bronchus is intubated.

14.3.2 Univent Tube

The Univent tube (Fuji Systems, Tokyo, Japan) is a tracheal tube with a second small lumen containing a bronchial blocker (BB). This second lumen can be advanced into the bronchus to be blocked under direct visualization. The BB is firmly attached to the tracheal tube to avoid accidental displacement and a small internal lumen allows lung deflation. Common problems encountered with this device are difficulty in ventilating patients because of the large diameter of the second lumen containing the blocker and the risk of mucosal damage caused by the cuff of the blocker.

14.3.3 Double-Lumen Tubes

Double-lumen tubes (DLTs) are designed as two tubes of unequal length molded together. The shorter tube ends in the trachea and the longer tube in the bronchus. Each lumen has a cuff. The tracheal cuff allows positive ventilation. The bronchial cuff allows separate lung ventilation and protection of each lung from any purulent blood coming from the opposite lung.

Inserting a DLT consists of inserting the tip of the tube through the vocal cords, withdrawing the stylet, rotating the tube 90° to the appropriate side, and then advancing the tip of the tube into the main bronchus. Fiberoptic bronchoscopy is used to confirm tube placement with the bronchial cuff into the main bronchus.

DLTs can be considered the gold standard for SLV. They allow the independent suction and ventilation of each lung and protect both lungs from contamination. Left-sided tubes are preferred to right-sided ones, as they are easier to insert and as right-sided tubes pose a significant risk of right upper lobe obstruction. The main limitation of DLTs is size, as the smallest commercially available size is suitable for teenagers but not younger patients. Therefore, small children cannot benefit from this technique.

14.3.4 The Arndt Bronchial Blocker

We recently published a pediatric case series involving the use of the Arndt BB [5]. The Arndt BB has been designed as a 5 Fr catheter with a distal spherical low-pressure balloon, and a lumen with an inner removable string that exits from the distal end of the catheter. The string can be looped over the fiberoptic scope with the aim of guiding the catheter into the bronchus that is to be blocked. In our study, following removal of the string, the lumen was used for gradual lung collapse at the beginning of thoracoscopy, and for oxygen delivery or aspiration of secretions during surgery. A multiport air adapter is provided with the Arndt BB and this was used to pass the fiberoptic scope and the BB through their respective ports into the tracheal tube (Fig. 14.1). The multiport was connected to the ventilation circuit to manually or mechanically ventilate the patient during the Arndt maneuver. The steps needed for the correct placement of the BB are described in Table 14.1.

The BB is positioned with the patient under general anesthesia. During the procedure, the patient can be ventilated mechanically or manually with 100% oxygen to minimize the risk of hypoxemia. An uncuffed tracheal tube as large as can be tolerated by the patient has to be inserted, with the aim of maximizing

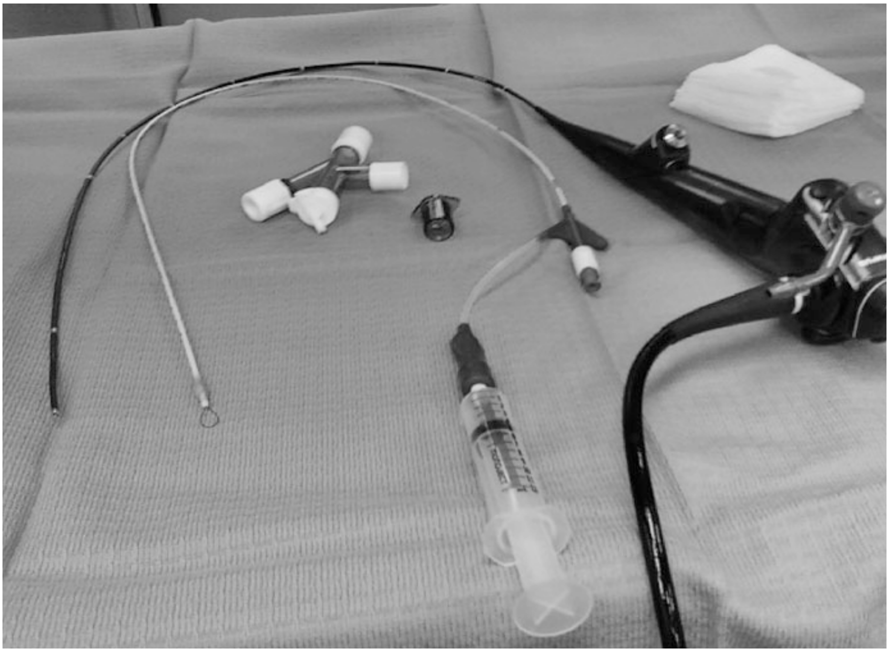

Fig. 14.1 Arndt 5 Fr bronchial blocker, multiport air adapter, and 2.7 mm fiberscope

Table 14.1 Steps for correct bronchial blocker (BB) positioning

1. The BB and scope are introduced through the ports.
2. The scope is passed into the loop of the BB.
3. The scope is advanced into the desired bronchus.
4. Correct identification of the bronchus to be blocked is made.
5. The BB is advanced over the tip of the scope.
6. The scope is pulled back until the carina is visible through the scope.
7. The BB is moved back to the main bronchus to be blocked.
8. The balloon is inflated under direct visualization (within a volume of air up to 2 mL).
9. Placement of the inflated balloon in the bronchus is confirmed by direct visualization and auscultation of lung separation.
10. The BB port is tightened following the removal of the fiberoptic scope to allow correct ventilation.

the space available for the maneuver with the fiberscope and BB inside the tube (Table 14.1).

In our study, we were able to achieve SLV in all patients of the case series. Placement required approximately 10–25 min. SLV was tolerated in all patients; a continuous positive flow of oxygen with a measured pressure of 10–15 cm H_2O was delivered into the blocked lung through the lumen of the Arndt BB in patients with reduced intraoperative tolerance of SLV. The main adverse event was

BB displacement, especially when patients were turned onto their side. For this reason, the BB can be safely placed in patients already turned onto their side for surgery in such cases. Except for the reported displacement, there were no reported complications from BB placement and SLV was successful even in very young patients.

14.4 Discussion

SLV is a helpful technique for thoracic surgery. It can be mandatory in the case of thoracoscopy, when the need for a good surgical view and enough space to maneuver have a significant impact on the final outcome. Different devices and techniques have been presented in this chapter, such as choosing the correct tube size (Table 14.2), but the two most reliable devices are the Arndt BB and the DLT. Considering the age of pediatric patients, the only commercially available option is the Arndt BB, as the smallest size of the DLT is only suitable for adolescents. We published a first study using a 5 Fr BB in children undergoing thoracoscopic surgery. The device has been shown to be a reliable method to achieve SLV, being extremely helpful for both thoracoscopy and video-assisted thoracic surgery in selected cases or for major lung surgery and surgery involving the mediastinal structures of relatively young patients, and several case series have been published [5–6]. Our experience suggests that BB should be used in young patients where the DLT cannot be used.

First, the main benefit of using the Arndt BB is that it can be passed through a standard tracheal tube; this should be easier to learn and master, especially in a large pediatric hospital where thoracic surgery is relatively frequent. All the anesthesiologists involved were interested in thoracic anesthesia and had specific expertise in airway management and pediatric bronchoscopy. For this reason, achieving proficiency in positioning a BB was relatively rapid and displacements were the only reported adverse events.

Table 14.2 Tube size selection for single-lung ventilation in infants, children, and teenagers

Age (years)	ETT (ID in mm)	BB (Fr)	Univent (ID in mm)	DLT (Fr)
0.5–1	3.5–4.0	5	–	–
1–2	4.0–4.5	5	–	–
2–4	4.5–5.0	5	–	–
4–6	5.0–5.5	5	–	–
6–8	5.5–6.5	5	3.5	24
8–10	6.0–6.5	5	3.5	26
10–12	6.5–7.0	5–7	4.5	26–28
12–14	7.0–7.5	5–7	4.5	32

BB bronchial blocker, *DLT* double-lumen tube, *ETT* endotracheal tube, *Fr* French size (medical tubing unit of measurement), *ID* inner diameter

A comparison between the BB and a different device, such as the DLT, has already been published in adults [7–8]. The authors concluded that each device provides advantages, depending on each specific case and that a "best" device does not exist. In particular, for absolute lung separation, the use of the DLT has been shown to be the best choice. On the other hand, the BB represents a better choice for patients with difficult airways or for selective lobar ventilation. A similar comparison is not feasible in children because of the lack of commercially available pediatric devices.

Second, the size of the tracheal tube and consequently the age and weight of the patient can be considered a limitation for performing lung separation with a BB. The smallest tracheal tube used in the present series had a 5.5 mm internal diameter (ID) and the blocker was positioned under direct visualization using a 2.8 mm fiberoptic scope. If a smaller tracheal tube were to be used, then a 2 mm fiberoptic scope would be required for the procedure. A recently published article [9] described the insertion of a 5 Fr BB outside the tracheal tube in an infant aged less than 1 year. Placing a BB outside the tracheal tube is an alternative option which can be applied in small children, but it is far from being routine clinical practice.

In our clinical practice, the tracheal tube connector is substituted with a larger one, outside the extremity of the tube. The connector between the tracheal tube and the breathing circuit is the narrowest point and the space to maneuver the scope and the BB can be limited, especially with the smaller tubes (5.5 mm ID or smaller). For this reason, the connector is routinely changed with a larger one, to be placed outside the tracheal tube and to increase the space to maneuver. A limitation of the technique is the risk of hypoxemia during the insertion of the BB and, intraoperatively, during SLV. We used mechanical or manual ventilation when positioning the BB, and all the patients were deeply anesthetized and immobilized. This was to minimize the risk of hypoxemia, even in the case of air leaking through the multiport. Once the BB was positioned and thoracoscopy started with the operative lung collapsed, a continuous positive airway pressure (CPAP) with a fresh flow of 1–2 L/min O_2 can be established and measured at a pressure of 10–15 cm H_2O, until the end of surgery and lung re-expansion. CPAP works by improving oxygenation. The ventilator can be set up using pressure-controlled ventilation to minimize the peak inspiratory pressure. Once SLV is started, the peak inspiratory pressure is adjusted to reduce the tidal volume to one-third of that used during double-lung ventilation. The fraction of inspired O2 and the respiratory rate are then adjusted to avoid hypoxemia and hypercarbia [3–4].

14.5 Conclusions

The main difficulty for the correct positioning of a BB is the acquisition of adequate skills in pediatric bronchoscopy and pediatric thoracic anesthesia. The identification of the correct bronchus to be blocked, viewing the upper lobe bronchus on the right or the upper and lower lobar bronchi on the left, knowledge of the devices (fiberoptic scope and BB), and rapid execution of the maneuvers are mandatory for all anesthesiologists involved in pediatric thoracoscopic surgery. The results from our wide-ranging experience in thoracic surgery shows that the Arndt 5 Fr BB is a consistent, reliable, and safe method for SLV in children undergoing thoracoscopic surgery; it can also be used in those cases where DLT ventilation is not suitable because of the young age and low weight of the patient.

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