Methods for Single-Lung Ventilation in Pediatric Patients

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Because many children are too small for double-lumen tubes (DLTs), other techniques are often required for single-lung ventilation (SLV) in pediatric patients. This article offers tube selection guidelines for SLV in children.

Methods

We reviewed published values for airway measurements in children (Table 1) (1,2). Data from the first study was derived by analyzing fresh autopsy specimens of intact tracheo-bronchial trees from 160 children between the ages of 6 mo and 16 yr (1). Thin cross-sections of the airways were made at various levels and photographed on color slides. By using a metric rule photographed with the specimen, measurements were read from the projected slides. The second set of data was obtained from chest computed tomographic examinations of 130 children from 1–21 yr of age (2).

The trachea is elliptical in shape, with the frontal diameter exceeding the sagittal diameter. Because the sagittal dimension is the "limiting" diameter and determines the largest tube that will fit, the sagittal measurement was used as our value for tracheal diameter. Data for bronchial dimensions were calculated using measured tracheal-to-bronchial ratios in children (3).

Tube dimensions were obtained from each manufacturer and by direct measurement by a biomedical engineer using calipers accurate to within 0.025 mm.

Results

The results of our review are shown in Table 1. Based on these data and the dimensions of tracheal tubes and bronchial blockers (Tables 2–5), recommendations for SLV are given in Table 6.

Discussion

The different SLV techniques that can be used in children are briefly reviewed.

Single Lumen Endotracheal Tube (ETT)

The simplest method is to intentionally intubate a mainstem bronchus with a conventional single-lumen ETT (4,5). The ETT is advanced into the bronchus until breath sounds over the contralateral (operative) lung disappear. A fiberoptic bronchoscope (FOB) can be passed through or alongside the ETT to confirm or guide placement. When a cuffed ETT is used, the distance from the tip of the tube to the proximal edge of the cuff must be shorter than the length of the mainstem bronchus to insure that the cuff is entirely in the bronchus (6).

This technique requires no special equipment other than a FOB. Problems include failure to achieve an adequate seal of the bronchus, especially if an uncuffed ETT is used. This may prevent the operated lung from collapsing completely or fail to protect the healthy, ventilated lung from contamination. One is unable to suction the operated lung. Hypoxemia may result from obstruction of the upper lobe bronchus, especially when the short right mainstem bronchus is intubated.

Variations of this technique have been described, including intubation of both bronchi independently with small ETTs (7–10). One mainstem bronchus is initially intubated with an ETT after which another ETT is advanced over a FOB into the opposite bronchus.

Balloon-Tipped Bronchial Blockers

We previously described bronchial blockade using an end-hole, balloon wedge catheter (Arrow International Corp., Redding, PA) (11). The bronchus on the operative side is initially intubated with an ETT. A guidewire is then advanced through the ETT into that bronchus. The ETT is then removed, and the blocker

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Table 1. Airway Dimensions in Children

Age (yr)	Trachea[a] (mm)	Expected right bronchial diameter (mm)	Expected left bronchial diameter (mm)	Trachea[b] (mm)	Expected right bronchial diameter (mm)	Expected left bronchial diameter (mm)
0.5–1	5.6	4.8	3.7	N/A	N/A	N/A
1–2	6.5	5.6	4.3	5.3	4.6	3.5
2–4	7.6	6.5	5.0	7.4	6.4	4.9
4–6	8.0	6.7	5.3	8.0	6.7	5.3
6–8	9.2	7.9	6.1	9.2	7.9	6.1
8–10	9.0	7.7	6.0	10.5	9.0	6.9
10–12	9.8	8.4	6.5	11.6	10.0	7.0
12–14	10.3	8.6	6.8	13.0	11.2	8.6
14–16	12.7	10.9	8.4	13.9	12.0	9.2
16–18	NA	NA	NA	13.7	14.6	9.0
18–20	NA	NA	NA	13.9	12.0	9.2

The average mean tracheal AP (saggital) diameters are given, as this dimension determines the "limiting diameter" (i.e., largest size tube admissable). The bronchial diameters are calculated from measured bronchial:tracheal ratios of 0.86 (right bronchus) and 0.66 (left bronchus) in children (1).
NA = not applicable.
[a] See Reference 1.
[b] See Reference 2.

Table 2. Single-Lumen Endotracheal Tube Diameters

ID (mm)[a]	OD (mm)
3.0	4.3
3.5	4.9
4.0	5.5
4.5	6.2
5.0	6.8
5.5	7.5
6.0	8.2
6.5	8.9
7.0	9.6

Cuffed tubes have approximately 0.5 mm additional outer diameter.
ID = internal diameter, OD = outer diameter.
[a] Sheridan® Tracheal Tubes, Kendall Healthcare, Mansfield, MA.

Table 3. Balloon Wedge Catheters[a] for Use as Bronchial Blockers in Children

French size (F)	Length (cm)	Maximal inflating capacity (mL)	Inflated balloon diameter (mm)	Guidewire size (in.)
5	60	0.75	8	0.025
6	60	1.0	10	0.035
7	110	1.25	11	0.038
8	110	1.25	11	0.038

[a] Arrow International Corp., Redding, PA.

catheter is advanced over the guidewire into the bronchus. The ETT is then reinserted into the trachea alongside the blocker catheter. Alternatively, a Fogarty embolectomy catheter may be placed with or without bronchoscopic guidance (12,13). A FOB is then used to confirm the position of the blocker.

With an inflated blocker balloon, the airway is completely sealed, providing more predictable lung collapse and better operating conditions than with an ETT in the bronchus.

A potential problem is dislodgement of the blocker balloon into the trachea. The inflated balloon will then block ventilation to both lungs and/or prevent collapse of the operated lung. The balloons of catheters used for bronchial blockade have low-volume, high-pressure properties, and overdistension can damage or even rupture the airway (14). When closed-tip bronchial blockers are used, the operated lung cannot be suctioned, and continuous positive airway pressure cannot be provided to the operated lung if needed.

Univent Tube

The Univent tube (Fuji Systems Corporation, Tokyo, Japan) is a conventional ETT with a second lumen containing a small tube that can be advanced into a bronchus (15). A balloon located at the distal end of this small tube, when inflated, serves as a blocker. Univent tubes require FOB for successful placement. Univent tubes are now available in sizes as small as a 3.5 and 4.5 mm internal diameter for children (16).

Because the blocker tube is firmly attached to the main ETT, displacement of the Univent blocker balloon is less likely than when other blocker techniques are used.

DLTs

All DLTs are essentially two tubes of unequal length molded together. The shorter tube ends in the trachea and the longer tube in a bronchus. Marraro (17) described a bilumen tube for infants. This tube consists of two separate uncuffed tracheal tubes of different length attached longitudinally. The Marraro tube is not available in the United States.

Table 4. Univent Tube[a] Diameters

ID (mm)	OD (mm)[b]
3.5	7.5/8.0
4.5	8.5/9.0
6.0	10.0/11.0
6.5	10.5/11.5
7.0	11.0/12.0
7.5	11.5/12.5
8.0	12.0/13.0
8.5	12.5/13.5
9.0	13.0/14.0

ID = internal diameter, OD = outer diameter.
[a] Fuji Systems Corporation, Tokyo, Japan.
[b] Values are sagittal/transverse.

Table 5. Double-Lumen Tube Dimensions

Size (F)	Main body OD (mm)	Bronchial lumen OD (mm)
26[a]	9.3	5.7
28[b]	10.2	6.9
32[b]	11.2	8.1
35[b]	13.5	9.7
37[b]	14.0	10.4

OD = outer diameter.
[a] Rusch, Inc. Duluth, GA.
[b] Mallinckrodt Medical, Inc., St. Louis, MO. (Cuff thickness is 0.049 mm; therefore, cuff adds 0.10 mm to overall OD of tube.)

Table 6. Tube Selection for Single-Lung Ventilation in Children

Age (yr)	ETT (ID)[a] (mm)	BB[b] (F)	Univent (ID)[c] (mm)	DLT[d] (F)
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	6	3.5	
8–10	6.0 cuffed	6	3.5	26
10–12	6.5 cuffed	6	4.5	26–28
12–14	6.5–7.0 cuffed	6	4.5	32
14–16	7.0 cuffed	7	6.0	35
16–18	7.0–8.0 cuffed	7	7.0	35

ETT = endotracheal tube, BB = bronchial blocker, ID = internal diameter, DLT = double-lumen tube.
[a] Sheridan® Tracheal Tubes, Kendall Healthcare, Mansfield, MA.
[b] Arrow International Corp., Redding, PA.
[c] Fuji Systems Corporation, Tokyo, Japan.
[d] 26F: Rusch, Duluth, GA; 28–35F: Mallinckrodt Medical, Inc., St. Louis, MO.

DLTs for older children and adults have cuffs located on the outer walls of the tracheal and bronchial lumens. The tracheal cuff, when inflated, allows positive pressure ventilation. The inflated bronchial cuff allows ventilation to be diverted to either or both lungs and protects each lung from contamination from the contralateral side.

In children, the DLT is inserted using the same technique as in adults (18). If FOB is to be used to confirm tube placement, a FOB with a very small diameter and sufficient length must be available. In adults, the depth of insertion is directly related to the height of the patient (19). No equivalent measurements are yet available in children.

A DLT offers the advantage of ease of insertion. One is able to suction and oxygenate the operative lung with continuous positive airway pressure. Left-sided tubes are preferred to right DLTs because of the shorter length of the right main bronchus. Right DLTs are more difficult to accurately position and have a greater risk of right upper lobe obstruction.

There are few reports of airway damage from DLTs in adults and none in children (20). Their high-volume, low-pressure cuffs should not damage the airway if they are not overinflated with air or distended with nitrous oxide while in place.

The sizes of DLTs that can be used in children are shown in Table 6. The recommendations are based on average values for airway dimensions. Larger DLTs may be safely used in large teenagers.

Isolation of the lungs and SLV in pediatric patients can be accomplished with a variety of tubes. The challenge to the anesthesiologist is to choose a safe and effective means for isolating the lungs in each individual patient.

We reviewed the normal values for tracheal and bronchial diameter by age. Because the right bronchus is slightly larger than the left, tubes that fit the left bronchus will also fit the right bronchus. Using the patient's age and airway measurements allows selection of the appropriate technique and tube. Individual patient characteristics must also be considered. Guidelines for selecting an appropriate lung isolation technique, based on the age of the patient or the tracheal diameter, are given. Prospective follow-up of these guidelines is necessary for complete assurance the guidelines are accurate.

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