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Original Article

A Retrospective Evaluation of Airway Anatomy in Young Children and Implications for One-Lung Ventilation

Martina G. Downard, MD[*,1], Amy J. Lee, MD[*], Christopher J. Heald, MD[†], Evelyn Y. Anthony, MD[†], Jasmeet Singh, MD[†], T. Wesley Templeton, MD[*]

[*]*Department of Anesthesiology, Wake Forest School of Medicine, Winston-Salem, NC*
[†]*Department of Radiology, Wake Forest School of Medicine, Winston-Salem, NC*

Objective: One-lung ventilation (OLV) in children remains a niche practice with few studies to guide best practices. The objective of this study was to describe lower airway anatomy relevant to establishment of OLV in young children.
Design: Retrospective, observational study using pre-existing studies in the electronic health record.
Setting: Single institution, academic medical center, tertiary-care hospital.
Participants: Pediatric patients <8 years old.
Interventions: None.
Measurements and Main Results: Chest computed tomographic scans of 111 children 4 days to 8 years of age were reviewed. Measurements were taken from the thyroid isthmus to the carina, carina to first lobar branch on the left and right, diameter of the trachea at the carina, and diameter of the left and right mainstem bronchi. Dimensions were correlated with the outer diameter of endotracheal tubes and bronchial blockers. The left mainstem bronchus is consistently smaller than the right. Lung isolation using a mainstem technique on the left should use an endotracheal tube a half size smaller than would be used for tracheal intubation. The length from the carina to the first lobar branch on the left is consistently 3 times longer than on the right. Further, age-delineated bronchial diameters suggest that the clinician should transition from a 5F to a 7F Arndt bronchial blocker at 3-to-4 years of age.
Conclusion: A more detailed and accurate understanding of pediatric lower airway anatomy may assist the clinician in successfully performing OLV in young children.

Key Words: single-lung ventilation; pediatric; lower airway anatomy; anesthesia

ONE-LUNG ventilation (OLV) in young children remains technically challenging. With the advancement of less-invasive thoracoscopic techniques, there continues to be an escalating need for OLV via endobronchial intubation or bronchial blocker placement.[1] Given this, it is important the clinician have some understanding of the anatomic constraints of the lower pediatric airway to safely and efficiently administer OLV.

One of the first attempts in the modern era to supply clinicians with this data was by Hammer in 1999, who provided an endotracheal tube (ETT) selection guideline for single-lung ventilation in children 0-to-20 years old based on a derivative analysis of pediatric airways from 1986 by Griscom et al. and airway measurements from a textbook, *Respiration and Circulation*, published in 1971.[2,3] In this analysis, Hammer estimated the diameter of each mainstem bronchus for different ages using the ratio of the tracheal diameter to mainstem bronchus diameter published in 1923 by Scammon in the journal *Pediatrics*.[4]

[1]*Address reprint requests to* Martina G. Downard, MD, Department of Anesthesiology, Wake Forest School of Medicine, Medical Center Boulevard, Winston-Salem, NC 27157-1009.

E-mail address: mdownard@wakehealth.edu (A.J. Lee).

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Prior to widespread utilization of high-resolution computed tomography (CT), pediatric airway measurements were estimated primarily by fiberoptic bronchoscopic evaluation or by examination of pediatric cadavers.[5-7] Both techinques, however, were limited to measuring only the upper airway in young children and were, in many cases, difficult to replicate.

More recently, high-resolution CT imaging has made it possible to assess *in vivo* lower pediatric airway dimensions with increased precision. One of the first studies looking at airway anatomy was published by Wani et al., in which the investigators performed a retrospective review of chest CT scans in children and cataloged how the cricoid ring and left mainstem bronchus varied with age.[8] However, the investigators' focus was not on how these measurements apply to the institution of OLV in young children. This is shown by the fact that the youngest patients were grouped into a single cohort from 0-to-1 year old, potentially oversimplifying significant growth-based changes that may affect various approaches to OLV in this age group. Additionally, other investigators have focused on upper airway dimensions in children, such as the diameter of the trachea and cricoid, but few studies evaluated the anatomy of the lower airways, defined as the trachea extending from the vocal cords to the primary and secondary bronchial segments.[9-12] It is this anatomy that is most relevant when determining the correct bronchial blocker or ETT for lung isolation in young children.[13]

Thus, the primary aim of this study was to catalog anatomic measurements of the lower airway in children <8 years of age and correlate this with the outer diameter of different size ETTs and various bronchial blockers to facilitate OLV. The secondary aim was to assess the distance from the vocal cords to the carina and first lobar branch to estimate an initial starting point at the oral aperture for depth of insertion of an ETT or extraluminal bronchial blocker for lung isolation.

Methods

After institutional review board approval, the authors identified 124 chest CT scans performed in children <8 years of age between January 2012 and August 2017. Written informed consent was waived by the institutional review board. Scans performed in intubated patients; patients with a supraglottic airway in place; and patients with a mediastinal mass, tracheostomy, or a genetic syndrome were excluded. Additionally, the authors excluded scans performed in patients with a tracheoesophageal fistula, diaphragmatic hernia, or vascular ring. Finally, the authors also excluded scans that contained evidence of pulmonary contusion, pneumothorax, and/or presence of a tumor distorting the anatomy of the lower airway. The scans were divided into age groups *a priori*. Children in the first year were divided into 0-to-3 months, 3-to-6 months, and 6-to-12 months to account for the rapid growth of the airway during this period of development. The remaining scans were divided by year to include 1-to-2 years, 2-to-3 years, up to 7-to-8 years of age.

All images were obtained in spontaneously breathing patients with or without sedation, with a native airway. All patients were positioned supine with arms at or above the level of the head per Department of Radiology chest imaging protocols. CT image resolution was standard among all studies, with 0.6 to 1.3-mm slice thickness and lung algorithm using a window setting of 1500 and level of −700 Hounsfield units.

Measurements were taken using electronic calipers. The length of the trachea was measured as the distance from the isthmus of the thyroid to the carina using coronal plane imaging. The isthmus of the thyroid was used because typically it corresponds to the level of the trachea just inferior to the level of the vocal cords, because the vocal cords frequently are not imaged in patients receiving only a chest CT at the authors' institution. Transverse measurements of the trachea at the carina were obtained in the horizontal plane. The carina was determined as the most distal symmetrical airway prior to branching into the bronchi. The diameters of the left and right mainstem bronchi were measured as the first perpendicular cross-section distal to the carina along the long axis of the bronchus using coronal plane images. The length from the carina to the proximal edge of the first lobar branch of the left and right mainstem bronchi was measured in the coronal plane. These measurements are illustrated in Figure 1.

Each measurement was performed independently by 2 authors for each patient and then was averaged. The tracheal lengths were measured by a pediatric anesthesiologist and anesthesia resident (M.D., A.J.). The bronchi diameters and length to first branching from the main bronchi were measured by a pediatric radiologist and radiology resident (E.A., C.H.) using more advanced viewing techniques to obtain accurate measurements of small bronchi. Any anatomic measurement that differed by >3 mm was subsequently reviewed again by 2 authors. In this situation, the original measurements were discarded and 2 new independent measurements were made and then averaged. This proved adequate to resolve all discrepancies.

For comparison, the external diameter of different size cuffed, uncuffed, and microcuff ETTs (Kimberly-Clark Health Care, Atlanta, GA) were taken from the manufacturer's specifications. Additionally, the authors recorded the diameter of the distal occlusive balloon of both the 5F and 7F Arndt bronchial blockers (Cook Medical, Bloomington, IN) when inflated to approximately 100 cmH_2O pressure. In an attempt to reflect actual clinical practice, 100 cmH_2O of pressure was used to standardize the measurements of the balloons and avoid inconsistency. The 5F and 7F Arndt bronchial blockers were inflated with 2.25 mL and 2.50 mL of air, respectively, to produce diameters of 6 mm and 7 mm for each balloon. Similarly, the diameters of the inflated 5F Fuji Uniblocker (Ambu, Columbia, MD) and 4F Fogarty embolectomy catheter (Edwards Life Sciences, Irvine, CA) were 6 mm with 2.50 mL of air and 6 mm with 0.75 mL of air, with inflation pressure of approximately 100 cmH_2O in both.

In developing an estimate of the proper depth of insertion from the lip for an ETT or bronchial blocker for OLV, the authors first calculated the normal depth of insertion for a cuffed ETT based on age (age/4 plus 3.5) and multiplied this by 3.[14-16] This length then was used to approximate the distance to 2.0 cm beyond the vocal cords. This distance then was added to the measurement of the trachea from the level of

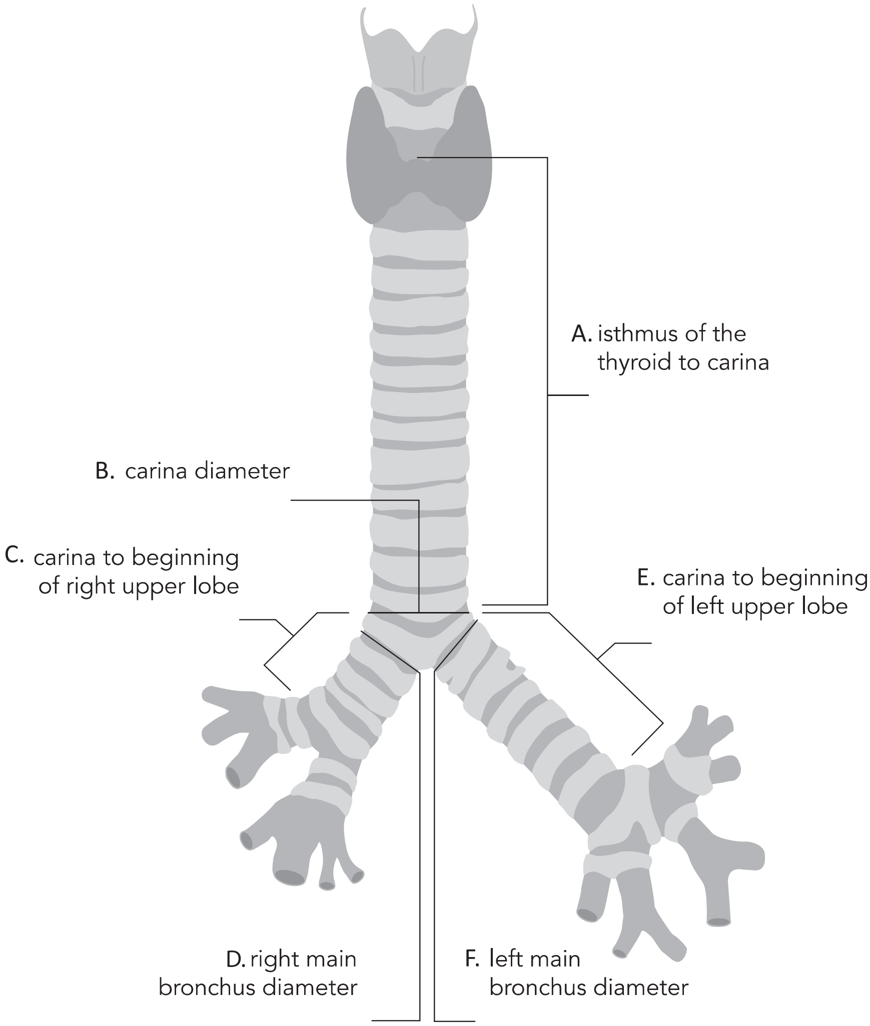

Fig 1. Diagram of lower airway measurements. (A) Isthmus of the thyroid to carina. (B) Carina diameter. (C) Carina to beginning of right upper lobe. (D) Right mainstem bronchus diameter. (E) Carina to beginning of left upper lobe. (F) Left mainstem bronchus diameter.

the isthmus of the thyroid to the carina, because the location of the isthmus of the thyroid varies from 1.0 cm below the vocal cords in infants and young children up to approximately 2.0 cm in older children. This relationship was measured in a smaller subset of patients in whom both the vocal cords and isthmus of the thyroid were included on the CT scan. Accordingly, the authors subtracted 1.0 cm in children ≤5 years of age when estimating the tracheal length. The total of these was defined as the length from the lip to the carina. Additionally, half the distance between the carina and the first lobar branch then was added to the calculated length from lip to the carina to derive an estimate of the depth of insertion at the lip. The depth of insertion for placement of a bronchial blocker similarly was calculated. An algebraic statement of this calculation is stated in the equation below:

$$ID * 3 + MTL + CL * 0.5 = \text{Depth at Lip(cm)}$$
$$ID = \text{internal diameter of age appropriate cuffed ETT(mm)}$$

MTL = measured tracheal length (cm) = thyroid isthmus to carina minus 1.0 cm in children ≤5 years of age or thyroid isthmus to carina only in children >5 years of age

CL = distance from carina to proximal edge of first lobar take off (cm)

Statistical Analysis

Descriptive statistics were performed on demographic data and all airway measurements. Airway data were presented as median and 25th and 75th percentile. Additionally, a post hoc linear regression model was performed using the age and calculated depth of insertion to achieve mainstem intubation. This model was transformed algebraically to develop a roughly equivalent value for insertion depth based solely on the internal diameter of an age-appropriate cuffed ETT to create the simplified formula. There were no missing data for any patients. All available patients meeting inclusion criteria were included for analysis.

Results

The authors identified 124 patients between the ages of 4 days and 8 years with CT imaging of the neck and chest. Of

Table 1
Left Mainstem Bronchial Diameters With Corresponding Device for OLV

Age	Left Mainstem Bronchus Diameter median (mm) (25-75)	ID Uncuffed ETT (OD mm)	ID Cuffed ETT (OD mm)	ID Microcuff ETT (OD mm)	5F Arndt BB*	7F Arndt BB*	4F Fogarty Embolectomand Catheter*	5F Fuji BB*
0-3 mo (n = 6)	3.6 (3.3-4.0)	2.5† (OD 3.6)	NA	NA	+	−	+	+
3-6 mo (n = 16)	3.9 (3.7-4.1)	2.5† (OD 3.6)	NA	NA	+	−	+	+
6-12 mo (n = 9)	4.2 (4.0-4.5)	3.0 (OD 4.2)	3.0 (OD 4.3)	3.0 (OD 4.3)	+	−	+	+
1-2 y (n = 12)	4.9 (4.4-5.4)	3.5 (OD 4.9)	3.5 (OD 4.9)	3.0 (OD 4.3)	+	−	+	+
2-3 y (n = 18)	5.1 (4.6-5.6)	3.5 (OD 4.9)	3.5 (OD 4.9)	3.5 (OD 5.0)	+	+/−	+	+
3-4 y (n = 7)	5.8 (5.5-6.3)	4.0 (OD 5.5)	4.0 (OD 5.6)	4.0 (OD 5.6)	+/−	+	+/−	+/−
4-5 y (n = 13)	6.1 (5.4-6.9)	4.0 (OD 5.5)	4.0 (OD 5.6)	4.0 (OD 5.6)	−	+	−	−
5-6 y (n = 10)	6.3 (6.0-7.5)	4.5 (OD 6.2)	4.5 (OD 6.2)	4.5 (OD 6.3)	−	+	−	−
6-7 y (n = 11)	6.8 (6.3-7.7)	4.5 (OD 6.2)	4.5 (OD 6.2)	5.0 (OD 6.7)	−	+	−	−
7-8 y (n = 9)	7.6 (6.9-8.7)	5.0 (OD 6.9)	5.0 (OD 6.9)	5.5 (OD 7.3)	−	+	−	−

NOTE. + = recommended device; − = not recommended, device either too large or risk of balloon hyperinflation.
Abbreviations: BB, bronchial blocker; ETT, endotracheal tube; ID, internal diameter; NA, not applicable; OD, outer diameter; OLV, one-lung ventilation.
* Balloon inflated to 100 cmH_2O.
† A 2.5 uncuffed endotracheal tube will fit theoretically; however, there may be practical considerations of increased resistance and short tube length. A 5F bronchial blocker may be a better choice in patients this age.

those, 13 were excluded, leaving 111 scans. Of the 13 scans that were excluded, 7 were excluded for intubation, 3 for congenital deformity, 2 for inadequate imaging, and 1 for pneumonia. The patients ranged in age from 4 days to 95 months, with 56 female patients and 55 male patients. Thirty-one scans were performed in children <12 months of age. The most common reasons for CT imaging were chest mass or nodule previously identified on chest x-ray (n = 27), trauma (n = 13), and persistent cough/shortness of breath (n = 13). Other diagnoses included fever, asthma, tumor, heart failure, and foreign body. The number of scans meeting inclusion criteria per prescribed age group ranged from 6-to-18, with a median of 11 per group. Overall, the rate of agreement among observers exceeded 80%% with most disagreements occurring in measurements of the bronchial diameter and length to first branching pattern.

Lower airway diameters are presented in Tables 1 and 2 along with the appropriate internal diameter (ID) of cuffed and uncuffed ETTs, bronchial blockers, and Fogarty embolectomy catheters based on age. Because clinicians may prefer or only have access to a certain device, various devices are listed. In all ages, the left mainstem bronchus diameter tends to be smaller in diameter than the right. As a result, the ID of the ETT for endobronchial intubation on the left should be 0.5-to-1.0 mm less than the standard calculated ETT size for age (age/4 + 3.5 for cuffed ETT or age/4.0 + 4.0 for uncuffed ETT) but equal to the standard calculated ETT size for age when performing a right-sided endobronchial intubation.

Suggested depths of placement from the lip for ETT or bronchial blocker are presented in Tables 3 and 4. Linear regression fitting and algebraic transformation of depth as a function of

Table 2
Right Mainstem Bronchial Diameters With Corresponding Device for OLV

Age	Right Mainstem Bronchus Diameter median (mm) (25-75)	ID Uncuffed ETT (OD mm)	ID Cuffed ETT (OD mm)	ID Microcuff ETT (OD mm)	5F Arndt BB*	7F Arndt BB*	4F Fogarty Embolectomy Catheter*	5F Fuji BB*
0-3 mo (n = 6)	4.4 (3.8-4.9)	3.0 (OD 4.2)	3.0 (OD 4.3)	3.0 (OD 4.3)	+	−	+	+
3-6 mo (n = 16)	4.7 (4.2-5.4)	3.0 (OD 4.2)	3.0 (OD 4.3)	3.0 (OD 4.3)	+	−	+	+
6-12 mo (n = 9)	5.4 (4.8-6.4)	3.5 (OD 4.9)	3.5 (OD 4.9)	3.5 (OD 5.0)	+	−	+	+
1-2 y (n = 12)	5.7 (5.4-6.4)	4.0 (OD 5.5)	4.0 (OD 5.6)	4.0 (OD 5.6)	+	−	+	+
2-3 y (n = 18)	6.2 (5.8-7.6)	4.5 (OD 6.2)	4.5 (OD 6.2)	4.5 (OD 6.3)	+/−	+/−	+/−	+/−
3-4 y (n = 7)	6.6 (5.5-7.3)	4.5 (OD 6.2)	4.5 (OD 6.2)	4.5 (OD 6.3)	−	+	−	−
4-5 y (n = 13)	7.6 (7.1-9.3)	5.0 (OD 6.9)	5.0 (OD 6.9)	5.5 (OD 7.3)	−	+	−	−
5-6 y (n = 10)	7.0 (6.5-8.9)	5.0 (OD 6.9)	5.0 (OD 6.9)	5.0 (OD 6.7)	−	+	−	−
6-7 y (n = 11)	8.1 (7.6-11.2)	5.5 (OD 7.5)	5.5 (OD 7.5)	5.5 (OD 7.3)	−	+	−	−
7-8 y (n = 9)	8.9 (8.1-10.7)	6.5 (OD 8.9)	6.5 (OD 8.9)	6.5 (OD 8.7)	−	+	−	−

NOTE. + = recommended device; − = not recommended, device either too large or risk of balloon hyperinflation
Abbreviations: BB, bronchial blocker; ETT, endotracheal tube; ID, internal diameter; NA, not applicable; OD, outer diameter; OLV, one-lung ventilation.
* Balloon inflated to 100 cmH_2O.

Table 3
Estimated Depth of Insertion for Endotracheal Tube or Bronchial Blocker From the Lip for Left-Sided Device Placement

Age (ETT ID)	Length of Left Mainstem Bronchus to First Lobar Branch (cm) Median (25-75 quartile)	Length of Trachea from Isthmus of Thyroid to Carina (cm) Median (25-75 quartile)	Recommended ETT Depth for Left Endobronchial Intubation or BB (cm)	Recommended ETT Depth for Left Endobronchial Intubation or BB Simplified formula (cm)
0-3 mo (3.0)	1.61 (1.38-1.78)	2.66 (2.20-3.08)	11.5	12.5
3-6 mo (3.0)	2.26 (1.99-2.47)	2.89 (2.69-3.15)	12.0	12.5
6-12 mo (3.5)	2.14 (1.86-2.52)	3.15 (2.72-3.44)	13.7	14.3
1-2 y (4.0)	2.43 (2.10-2.70)	3.63 (3.02-3.87)	15.8	16.0
2-3 y (4.5)	2.73 (2.48-2.78)	3.72 (3.43-4.26)	17.6	17.8
3-4 y (4.5)	2.70 (2.53-3.45)	4.16 (3.88-4.59)	18.0	17.8
4-5 y (5.0)	3.03 (2.81-3.38)	4.29 (4.04-4.46)	19.8	19.5
5-6 y (5.0)	3.18 (2.95-3.50)	4.64 (4.18-5.39)	20.2	19.5
6-7 y (5.5)	3.21 (3.03-3.34)	4.18 (4.18-5.59)	22.3	21.3
7-8 y (5.5)	3.44 (3.20-3.78)	4.46 (4.46-5.13)	22.7	21.3

NOTE. Recommended Initial Depth = (cuffed ETT sized for standard oral intubation × 3) + tracheal length − (1.0 cm for ≤5 year old or −0.0 for >5 years old) + (1/2 * distance from carina to first lobar branch in cm).
Abbreviations: BB, bronchial blocker; ETT, endotracheal tube; ID, internal diameter.

Table 4
Estimated Depth of Insertion for Endotracheal Tube or Bronchial Blocker From the Lip for Right-sided Device Placement

Age (ETT ID)	Length of Right Mainstem Bronchus to First Lobar Branch (cm) Median (25-75 Quartile)	Length of Trachea from Isthmus of Thyroid to Carina (cm) Median (25-75 Quartile)	Recommended ETT Depth for Right Endobronchial Intubation or BB (cm)	Recommended ETT Depth for Right Endobronchial Intubation or BB Simplified formula (cm)
0-3 mo (3.0)	0.58 (0.52-0.66)	2.66 (2.20-3.08)	11.0	11.5
3-6 mo (3.0)	0.60 (0.48-0.75)	2.89 (2.69-3.15)	11.2	11.5
6-12 mo (3.5)	0.63 (0.51-0.75)	3.15 (2.72-3.44)	13.0	13.3
1-2 y (4.0)	0.71 (0.59-0.85)	3.63 (3.02-3.87)	15.0	15.0
2-3 y (4.5)	0.65 (0.54-0.82)	3.72 (3.43-4.26)	16.5	16.8
3-4 y (4.5)	0.70 (0.64-0.83)	4.16 (3.88-4.59)	17.0	16.8
4-5 y (5.0)	0.76 (0.59-0.92)	4.29 (4.04-4.46)	18.7	18.5
5-6 y (5.0)	0.8 (0.70-1.05)	4.64 (4.18-5.39)	19.0	18.5
6-7 y (5.5)	1.1 (0.78-1.17)	4.18 (4.18-5.59)	21.2	20.3
7-8 y (5.5)	0.92 (0.82-1.15)	4.46 (4.46-5.13)	21.4	20.3

NOTE. Recommended Initial Depth = (cuffed ETT sized for standard oral intubation × 3) + tracheal length − (1.0 cm for ≤5 year old or −0.0 for >5 years old) + (1/2 * distance from carina to first lobar branch in cm).
Abbreviations: BB, bronchial blocker; ETT, endotracheal tube; ID, internal diameter.

ID of cuffed ETT resulted in a more simplified expression for depth of insertion.

$$\text{Left}-\text{side OLV}: \text{ Depth of placement (cm)} = ([3.5 * \text{age}-\text{appropriate cuffed ETT for oral intubation}] + 2)\text{ cm}$$

or

$$\text{Right}-\text{side OLV}: \text{ Depth of placement(cm)} = ([3.5 * \text{age}-\text{appropriate cuffed ETT for oral intubation}] + 1)\text{cm}$$

These simplified expressions correlated reasonably well with the depths calculated by the longer formula in most age groups, although the difference in these estimates increased in children aged 6 years and older. Additionally, one advantage of the simplified formula was they did not require knowledge of the tracheal length or length to first lobar branch from the mainstem bronchus. Finally, the distance from the carina to the first lobar branch of the left mainstem bronchus is approximately 3 times the length to the first lobar branch of the right mainstem bronchus regardless of age, which allows for an increased margin of error when placing a device in the left mainstem.

Discussion

The primary findings of this study included a catalog of *in vivo* measurements of the lower airway in children <8 years of age and correlating these measurements with different devices and ETTs to aid the clinician in selecting an appropriately sized ETT or bronchial blocker for OLV. Additionally, the findings gave the clinician a guide to estimate initial insertion depth of either an ETT or bronchial blocker to achieve lung isolation based on ETT size for standard oral intubation.

These findings were important, because proper sizing of an ETT, especially in small infants (<1 year of age), may reduce the incidence of airway trauma and improve bronchial seal when performing an endobronchial intubation for lung isolation. For example, a patient between 0 and 3 months has a median left mainstem diameter of 3.6 mm and median right mainstem diameter of 4.4 mm. Thus, placement of a 3.0 uncuffed ETT into the right mainstem bronchus is likely appropriate. In contrast, it may not be prudent to use a 3.0 uncuffed ETT to perform a left-sided endobronchial intubation in the same infant, because the ETT is relatively oversized, with an outer diameter of 4.2 mm. In this case, it is advisable to use a right-sided 5F bronchial blocker to reduce the chance of bronchial trauma. Theoretically, the clinician could use a 2.5 uncuffed ETT placed in the left mainstem; however, this may have significant issues including increased resistance to air movement as well as a short length. The clinician, however, should be aware the outer diameter of individual ETTs can vary significantly by manufacturer, so it is important to review the outer diameter of a given ETT prior to using it to perform OLV via endobronchial intubation to assure it is sized appropriately.[17] Additionally, the stated measurements in this study were medians based on a sample population, thus any individual patient may have a smaller or larger broncial diameter that might necessitate using a slightly larger or smaller ETT. Therefore, it is prudent to review a preoperative chest CT when available prior to instituting OLV in children undergoing thoracic surgery. Because not all children will have a recent preoperative CT scan, a reference for lower airway measurements by age is a useful starting point to determine the proper size device for endobronchial intubation.

Applying these findings to bronchial blockers, the occlusive balloon on the 5F Arndt blocker, with a diameter of 6 mm when inflated to 100 cmH_2O, is appropriate up to around 4 years of age regardless of which side the clinician is attempting to isolate. Across this age range, though, there is some variance in the compliance of a given occlusive balloon and frequently distention of the occlusive balloon of the 5F blocker to an extent that will achieve bronchial occlusion even in very young infants may require volumes between 2 and 4 mL with inflation pressures between 50 and 100 cmH_2O.[18] In this setting, the clinician should remain cautious when inflating these devices and adjust the inflation volume as necessary, inflating the occlusive balloon under direct vision. Further, although it is possible that additional inflation may enlarge the balloon to extend its use to larger children, overinflation potentially can lead to an increased risk of bronchial mucosal injury or blocker herniation into the trachea and cause tracheal occlusion.[19]

These findings also can be used to form an initial estimate of the ETT or bronchial blocker depth to achieve lung isolation. This information is important, for example, when performing an endobronchial intubation in an 18-month-old, as the distance from the carina to the takeoff of the right upper lobe is, on average, one-third shorter than that observed from the carina to the takeoff on the left upper lobe. As a result, the estimated placement depth measured at the patient's lip based on these airway measurements is approximately 1.0- cm different, 15.8 cm versus 15.0 cm. Further, the increased distance from the carina to first lobar branch may allow for a larger range of depth for successful lung isolation while avoiding occlusion of the left upper lobe. Although these measurements provided a reasonable estimate of device depth in several infants undergoing OLV at the authors' institution after the conclusion of this study, the clinician will have to finetune the depth of the chosen device in the operating room with clinical skills including auscultation and possibly flexible fiberoptic bronchoscopy or fluoroscopy. These data, however, can improve the accuracy of initial device placement and potentionally decrease the chance of injury due to excessive depth of placement, especially if placement is performed blindly or under the guidance of auscultation alone.

The results for the diameters of the carina and mainstem bronchi agreed closely with recent publications by Wani, Kuo, and Szelloe, which have reported airway dimensions including the carina, trachea, and right and left mainstem bronchus diameters.[8,20-23] This study, however, departed from prior studies by including increased numbers of patients as well as a greater number of children younger than 1 year, which allowed for further subdivision in that age range. This is important because establishing OLV frequently increases in difficulty as the age of the child decreases, making the anatomic information very useful in guiding device selection and depth.

Limitations

The primary limitation of this study was its retrospective design and small number of patients. However, this study included a larger number of children <1 year old than other published studies. It is reassuring in this study, though, that the diameters of the carina, the left mainstem bronchus, and the right mainstem bronchus agreed closely with values published by Kuo and Szelloe.[22,23] Additionally, it would have been preferable to use the cricoid or vocal cords as the proximal landmark for measuring the tracheal length; however, the vocal cords are not imaged consistently at the authors' institution when performing a chest CT. Fortunately, there is a fairly consistent 2-cm relationship between the vocal cords and the isthmus of the thyroid for children >5 years old, and a 1-cm relationship for children <5 years old, to allow for a more accurate estimation for depth of placement. In addition, sedation necessary to obtain a CT scan in a young child may affect airway measurements due to decreased airway tone; nonetheless, if lung isolation is being implemented, the child likely will require sedation. Further, the formulae created to calculate initial device depth using these measurements represent only a first estimate and the clinician likely will need to make appropriate individual adjustments to achieve lung isolation. Finally, although no prior study has shown a significant difference, it is possible that factors, such as height, sex, or ethnicity, may influence airway size in young children, and a larger subgroup sample size may refine measurements based on those criteria. Although lower airway dimensions in adult patients may vary by sex, if differences exist in children <8 years of age, they appear to be fairly small.[2,23] This lack of difference has been demonstrated in 2 other prior studies in which the investigators did not find a significant difference based on sex, height, or weight.[8,20]

Conclusion

In conclusion, this study provided the practicing clinician with age-specific data to further optimize device choice and initial insertion depth when performing lung isolation in children <8 years of age. Additionally, these preoperative measurements, when applied to an individual patient, may be helpful in determining proper size of the device used for OLV. More prospective study is necessary to validate these observations and their efficacy in clinical practice.

Conflict of Interest

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