CHEST
Original Research
INTERVENTIONAL PULMONARY

The Effects of Flexible Bronchoscopy on Mechanical Ventilation in a Pediatric Lung Model*

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Background: **Flexible bronchoscopy performed through endotracheal tubes (ETTs) in children receiving mechanical ventilation can significantly impact ventilation, but the magnitude of this impact has not been established. We used a lung model to simulate mechanical ventilation in a range of child sizes in order to determine how the insertion of pediatric flexible bronchoscopes into ETTs alters ventilatory parameters, especially tidal volume (VT) and peak inspiratory pressure (PIP), in both healthy and diseased lungs.**
Methods: **We simulated five child sizes based on weight, and evaluated 22 bronchoscope/ETT combinations, first in pressure control (PC) ventilation mode and then in volume control (VC) ventilation mode. The combinations ranged from the 2.2-mm (bronchoscope outer diameter)/3.0-mm (ETT inner diameter) to 5.0-mm bronchoscope/8.0-mm ETT. The primary outcome measures were decrease in VT after bronchoscope insertion during PC ventilation and increase in PIP during VC ventilation.**
Results: **In the PC ventilator mode, VT decreased by > 50% with nine of the combinations, while during VC ventilation, PIP increased by ≥ 20 cm H_2O with seven combinations. The 2.2-mm bronchoscope/3.0-mm ETT, 2.8-mm bronchoscope/5.0-mm ETT, and 3.6-mm bronchoscope/5.0-mm ETT combinations severely impaired ventilation, while the 3.6-mm bronchoscope/4.5-mm ETT, 5.0-mm bronchoscope/6.5-mm ETT, and 5.0-mm bronchoscope/7.0-mm ETT combinations were incompatible with adequate ventilation.**
Conclusions: **The insertion of bronchoscopes into ETTs can lead to clinically relevant decreases in VT when in the PC ventilator mode and large increases in PIP during VC ventilation. The minimum bronchoscope/ETT diameter difference required to maintain adequate ventilation increases with child size.** ***(CHEST 2009; 135:33–40)***

Key words: children; flexible bronchoscopy; mechanical ventilation

Abbreviations: CV = coefficient of variation; ETT = endotracheal tube; FRC = functional residual capacity; PC = pressure control; PEEP = positive end-expiratory pressure; PIP = peak inspiratory pressure; VC = volume control; VT = tidal volume

Flexible bronchoscopy is performed in intubated children receiving mechanical ventilation for a variety of reasons, including assessment of airway malacia and obstruction as well as acquisition of bronchoalveolar samples.[1,2] When a bronchoscope is inserted through an endotracheal tube (ETT), it affects many ventilatory parameters, including resistance across the ETT, flow rates, and alveolar and peak inspiratory pressures (PIPs). Thus, it is important to determine these effects and identify bronchoscope/ETT combinations that profoundly inhibit effective ventilation. In addition, it is important to establish the best mode of ventilation to use (*eg*, volume control [VC] or pressure control [PC]) when performing flexible bronchoscopy in mechanically ventilated children and infants.

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The impact on bronchoscope placement through ETTs during mechanical ventilation has been studied in adults and shown to cause significant reductions in tidal volume (VT) and changes in PIP, especially as the bronchoscope-ETT diameter differ-

Table 1—*Ventilator and Lung Model Settings by Weight-Based Model Size**

Ventilator Settings by Model Size					Lung Model Settings			
Model Size, kg	IMV, Breaths/min	PIP, cm H_2O	PEEP, cm H_2O	Inspiratory Time, s	Goal VT, mL	Compliance, mL/cm H_2O	Resistance, cm H_2O/L/s	FRC, mL
4	30	15	5	0.4	25	6	25	200
15	20	20	5	0.6	110	15	20	450
30	20	20	5	0.8	200	30	10	900
50	20	20	5	0.9	350	40	5	1500
70	20	20	5	1.0	500	45	3	2100

*In PC ventilation, the set PIP-generated VT of 6 to 7 mL/kg. In the VC mode, the VT was set at 7 mL/kg and generated PIPs of 15 cm H_2O in the infant (4 kg) model and approximately 20 cm H_2O in the other models. IMV = intermittent mandatory ventilation.

ence decreases.[3,4] There are limited data on the effects of flexible bronchoscopy on mechanical ventilation in children, and while studies in adults provide some insight, it is difficult to extrapolate these findings to children. In children and infants receiving mechanical ventilation, inspiratory times, flow rates, and VT are quite different from those in adults. The primary goal of our study was to determine the effects of the insertion of flexible bronchoscopes into ETTs on delivered VT in the PC mode of ventilation, change in PIP in the VC mode of ventilation, and generated auto-positive end-expiratory pressure (PEEP), using a lung model that simulates normal and abnormal respiratory mechanics.

Materials and Methods

The Lung Model

We used a digitally controlled, high-fidelity breathing simulator (ASL 5000; IngMar Medical; Pittsburgh, PA) to simulate respiratory mechanics in children of sizes ranging from infant through young adult. We designed five models with different lung sizes based on weight (4, 15, 30, 50, and 70 kg). We selected lung compliance and airway resistance values that corresponded to "healthy" lungs[5,6] (Table 1). In addition, we assessed the effects of flexible bronchoscopy in obstructive and restrictive lung disease using the 15-kg lung model size and the single combination of a 2.8-mm bronchoscope and 4.5-mm ETT. We modeled lung disease by adjusting airway resistance, lung compliance, and the functional residual capacity (FRC) of the model (Table 2). We chose these lung model settings either by referenced values or by measurements that we feel have been commonly observed in the clinical setting for mechanically ventilated patients of this size.[5,6] Mechanical ventilation was performed with the AVEA ventilator (Viasys; Yorba Linda, CA), which was connected to the ETT and lung model using standard ventilator tubing (Fig 1).

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This article was presented in part at the 2007 International Conference of the American Thoracic Society, San Francisco, CA, May 18–23, 2007.
The authors have reported to the ACCP that no significant conflicts of interest exist with any companies/organizations whose products or services may be discussed in this article.
Manuscript received April 14, 2008; revision accepted September 3, 2008.

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DOI: 10.1378/chest.08-1000

Bronchoscope/ETT Combinations

We evaluated 22 bronchoscope/ETT combinations (Table 3). The flexible bronchoscopes ranged from outer diameters of 2.2 to 5.0 mm, and the ETT sizes ranged from inner diameters of 3.0 to 8.0 mm (Table 2).

Measurement Devices, Calibrations, and Resistance Calculation

Our primary measures of interest were VT, PIP, and auto-PEEP. We also measured inspiratory and expiratory flow rates, alveolar pressures, and resistance across the ETTs, both with and without the bronchoscopes in place. Pressures were measured continuously with transducers (XRA515GN; Honeywell; Morristown, NJ). Inspiratory and expiratory flows were measured using pneumotachometers (Hans Rudolph; Kansas City, MO) connected to a differential pressure transducer (XCAL5004DN; Honeywell). The lung model provided readings for alveolar pressure, which we used to determine auto-PEEP. For each breath, flow resistance was calculated using a linear regression of pressure drop across the ETT vs flow throughout exhalation. VT was obtained by digitally integrating flow.

Table 2—*Lung Model Settings for Obstructive and Restrictive Models**

Models	Goal VT, mL	Compliance, mL/cm H_2O	Resistance, cm H_2O/L/s	FRC, mL
Normal	135	15	20	450
Obstructive	135	15	50	900
Restrictive	135	7.5	20	225

*Only the 15 kg size model and 2.8 mm bronchoscope/4.5 mm ETT combination were used. The ventilator settings were as follows: PC mode: IMV, 20 breaths/min; PIP, 20 cm H_2O; PEEP, 5 cm H_2O; and inspiratory time, 0.6 s; VC mode: IMV, 20 breaths/min; VT, 135 mL; PEEP, 5 cm H_2O; and inspiratory time, 0.6 s.