

# Heliox During Mechanical Ventilation

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**The indications for heliox during mechanical ventilation are lower-airway obstruction, especially with hypercarbia; need to enhance aerosol delivery to lung periphery; and need to facilitate weaning from mechanical ventilation. Certain ventilators perform relatively well with heliox and are not substantially affected by it. It is preferable to connect the heliox to the air inlet of the ventilator, because this results in more consistent delivery of oxygen and tidal volume. When administering heliox, pay close attention and directly monitor the actual tidal volume and fraction of inspired oxygen.** *Key words: chronic obstructive pulmonary disease, heliox, mechanical ventilation, noninvasive positive-pressure ventilation.* [Respir Care 2006;51(6):632–639. © 2006 Daedalus Enterprises]

## Introduction

Helium-oxygen mixtures (heliox) have been used in mechanically ventilated patients with airway obstruction. Heliox has been used with conventional ventilators, high fre-

quency ventilators, and noninvasive ventilators. For ventilators that have not been designed for use with heliox, technical concerns with the performance of the ventilator in the presence of heliox must be considered. This paper addresses the physiologic and technical aspects of heliox delivery during mechanical ventilation.

### Prediction of Physiologic Changes With Heliox During Mechanical Ventilation

Slutsky et al<sup>1</sup> published a detailed experimental investigation of steady flow through a realistic model of human lungs. Papamoschou, using the data from Slutsky et al, constructed a simplified fluid-mechanical model of the lungs to predict the behavior of various gases in the lower airways.<sup>2</sup> Based on heliox's known properties, we can predict the behavior of respiratory system mechanics and the performance of flow meters and ventilators during me-

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Shekhar T Venkataraman MD presented a version of this paper at the symposium, "Heliox Therapy: Practice, Evidence, Risk, and Opportunities," at the 51st International Respiratory Congress of the American Association for Respiratory Care, held December 3–6, 2005, in San Antonio, Texas.

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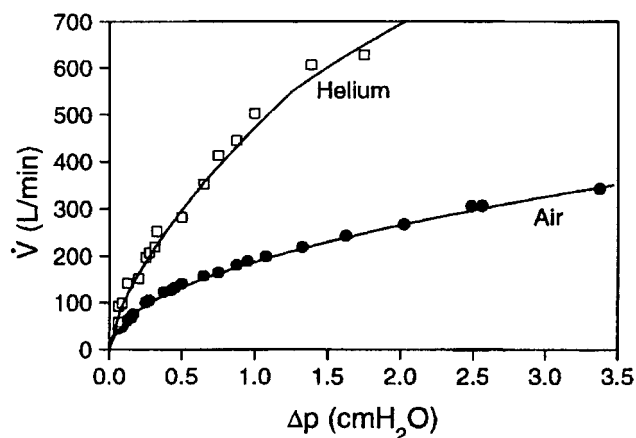


Fig. 1. Flow ( $\dot{V}$ ) versus change in pressure ( $\Delta p$ ) with air and helium in a lung model. (From Reference 2, with permission.)

chanical ventilation with heliox. Briefly, during turbulent gas flow, when transairway pressure is held constant, heliox will have a higher flow through the airways than will air or air-oxygen mixtures. The higher the concentration of helium, the higher the flow (compared to air or air-oxygen at a given pressure) (Fig. 1). At a given flow, the transairway pressure will be lower with heliox than with air or air-oxygen. The higher the concentration of helium, the lower the pressure. A density-dependent flow transducer that is calibrated for air or air-oxygen will give an inaccurately low flow reading with heliox. Breathing heliox decreases air-trapping in (and hyperinflation of) the lungs (caused by lower-airway obstruction), thereby reducing intrinsic positive end-expiratory pressure (PEEP). Heliox decreases dyspnea and work of breathing, and improves distal-airway deposition of aerosol particles.

### Lower-Airway Obstruction

Several prospective and retrospective studies have found heliox beneficial during mechanical ventilation of patients with lower-airway obstruction. No randomized controlled trials have compared heliox with air-oxygen during status asthmaticus or chronic obstructive pulmonary disease (COPD); all the published studies are either prospective case studies or retrospective analyses.

In a prospective study by Gluck et al,<sup>3</sup> heliox reduced peak airway pressure and  $P_{aCO_2}$  and helped correct respiratory acidosis in 7 intubated patients with status asthmaticus. Kass and Castriotta<sup>4</sup> had similar findings with a group of 12 patients, five of whom were mechanically ventilated. Schaeffer et al<sup>5</sup> reported that heliox improved the alveolar-arterial oxygen difference in 11 adult and pediatric patients mechanically ventilated for status asthmaticus. On the other hand, Gross et al<sup>6</sup> found that in children mechanically ventilated for bronchiolitis, heliox did not improve

oxygenation. Abd-Allah et al<sup>7</sup> published a retrospective study of the use of heliox in 28 mechanically ventilated children with status asthmaticus, all of whom received volume-controlled ventilation with a Siemens Servo 900C ventilator. Heliox was associated with significantly lower mean peak inspiratory pressure and mean  $P_{aCO_2}$ , and improvement in arterial pH.

Gerbeaux et al<sup>8</sup> retrospectively studied 81 patients who were admitted for exacerbation of COPD and respiratory acidosis. In this nonrandomized uncontrolled clinical study, 39 patients received 70:30 heliox (ie, a mixture of 70% helium and 30% oxygen) and 42 did not receive heliox. There were no significant differences in age, gender, medical history, other treatments, clinical cardiorespiratory variables, or gas exchange on admission to the emergency department. Among those who received heliox, the intubation rate was lower (8% vs 50%,  $p < 0.01$ ), mortality was lower (3% vs 24%,  $p < 0.01$ ), and intensive-care-unit (ICU) admissions were nonsignificantly lower (46% vs 60%,  $p = 0.23$ ). Among the survivors, mean ICU stay was shorter (8 vs 18 d,  $p < 0.01$ ).

Tassaux et al<sup>9</sup> reported a prospective interventional study performed in a medical ICU, which included 23 intubated, sedated, paralyzed, and mechanically ventilated patients with COPD who were enrolled within 36 h after intubation. Heliox was associated with a mean reduction in trapped lung volume of 116 mL (a 54% reduction), intrinsic PEEP of 4 cm H<sub>2</sub>O (a 45% reduction), peak airway pressure of 5 cm H<sub>2</sub>O (a 17% reduction), and mean airway pressure of 1 cm H<sub>2</sub>O (a 12.5% reduction) (Fig. 2). These variables all rose to their baseline values on cessation of heliox. There were no significant differences in arterial blood gases, heart rate, mean systemic arterial blood pressure, pulmonary artery pressure, right- or left-ventricular filling pressure, cardiac output, pulmonary or systemic vascular resistance, or venous admixture. More recently, Jolliet et al<sup>10</sup> found that in patients with COPD on mechanical ventilation, heliox reduced intrinsic PEEP, trapped gas volume, and the inspiratory and expiratory resistance of the respiratory system. Heliox did not significantly affect the ventilation-perfusion relationships.

Patients with lower-airway obstruction and air trapping may exhibit pulsus paradoxus, which increases in severity as the hyperinflation gets worse. Lee et al<sup>11</sup> found that heliox improves hemodynamics in mechanically ventilated patients with COPD and systolic pressure variations (Fig. 3). In a prospective, interventional study involving 25 mechanically ventilated patients with severe COPD and acute respiratory failure who had systolic pressure variations  $> 15$  mm Hg, heliox decreased trapped lung volume and intrinsic PEEP. Concomitantly, the respiratory changes in systolic arterial pressure variations decreased from 29.5% to 13.7%. In the 10 patients with pulmonary arterial catheters, heliox decreased mean pulmonary arterial pressure,

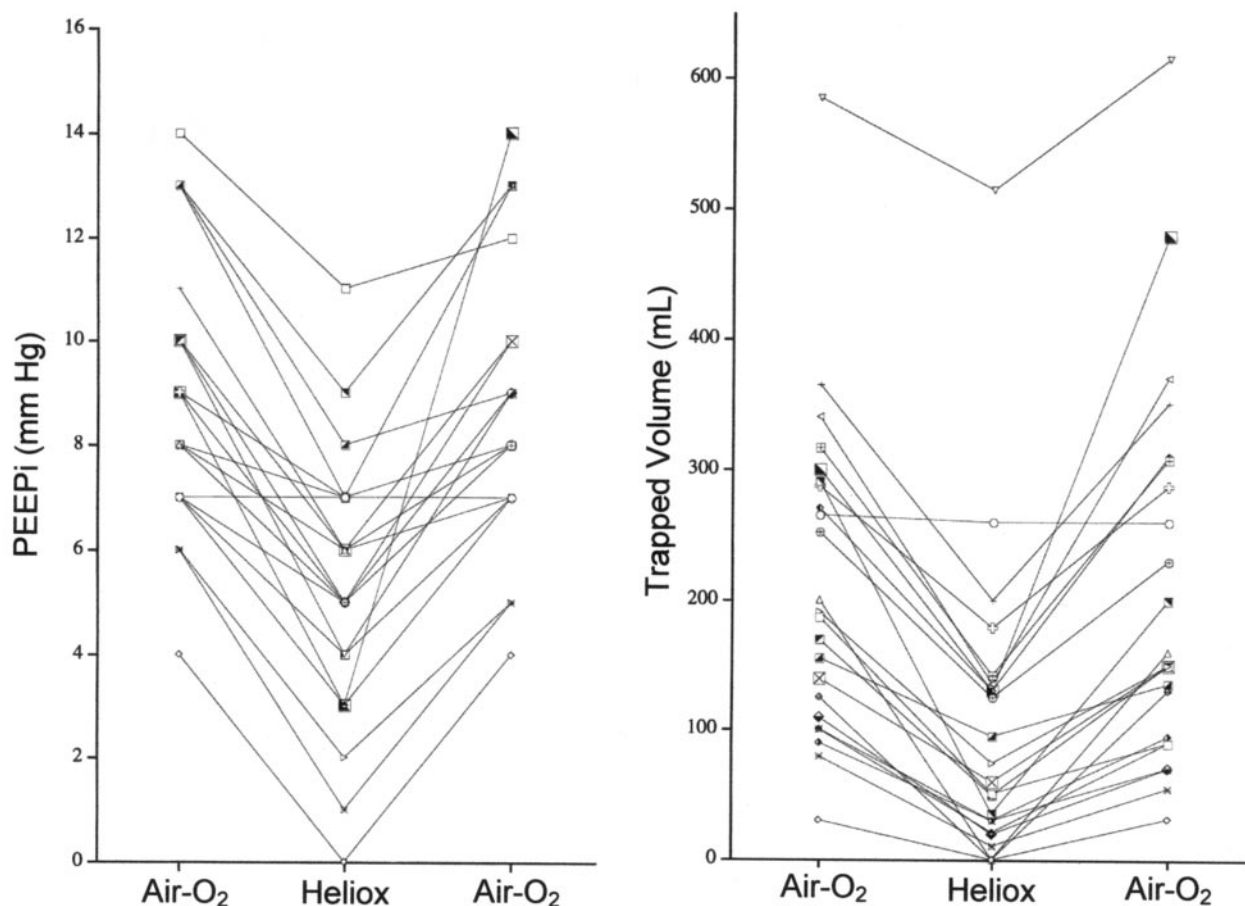


Fig. 2. A: Individual measurements of intrinsic positive end-expiratory pressure (PEEPi) before, during, and after administration of helium-oxygen mixture (heliox). B: Individual measurements of trapped end-expiratory lung volume before, during, and after administration of helium-oxygen mixture (heliox). (Adapted from Reference 9, with permission.)

right atrial pressure, and pulmonary arterial occlusion pressure, and heliox increased cardiac index. Pre-heliox pulse pressure correlated with the magnitude of reduction in intrinsic PEEP during heliox ventilation. Age, pre-heliox  $P_{aCO_2}$ , and the ratio of the forced expiratory volume in the first second to forced vital capacity correlated inversely, whereas pre-heliox pulse pressure correlated positively with increases in cardiac index.

#### Noninvasive Ventilation With Heliox

Noninvasive positive-pressure support with heliox reduces the work of breathing during a COPD exacerbation. Jolliet et al hypothesized that combining heliox with noninvasive ventilation would benefit decompensating COPD patients, and they found that noninvasive positive-pressure support with heliox decreased  $P_{aCO_2}$  and dyspnea.<sup>12</sup> Subsequently, they performed a prospective randomized multicenter study that found that noninvasive ventilation with heliox decreased post-ICU stay by about 6 days and decreased the total cost of hospitalization.<sup>13</sup>

#### High-Frequency Oscillation

The combination of heliox with nonconventional ventilation modes has been investigated in animal studies. In an animal model of acute lung injury, Katz et al<sup>14</sup> found that high-frequency oscillation with heliox improved oxygenation and ventilation. A subsequent study by the same investigators using the same animal model found that when the tidal volume ( $V_T$ ) delivered during high-frequency ventilation with heliox was controlled to the same level as during ventilation with air-oxygen mixture, there was no difference in gas exchange.<sup>15</sup> Therefore, the improvement seen in the first study was related to the larger  $V_T$  delivery by the oscillator with heliox.

#### Effect of Heliox on Aerosol Delivery and Nebulizer Functioning During Mechanical Ventilation

Currently available nebulizers are designed to be powered by air, oxygen, or air-oxygen mixture, so nebulizer performance is affected by using heliox to power the neb-

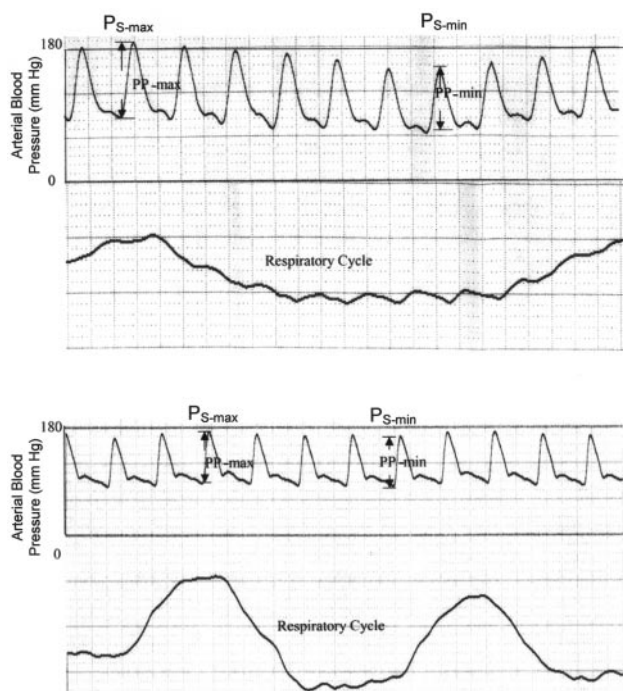


Fig. 3. Pulse pressure tracings within a respiratory cycle during mechanical ventilation with air-oxygen (top) and helium-oxygen mixture (bottom). The maximum systolic pressure ( $P_{S-max}$ ) and maximum pulse pressure ( $P_{P-max}$ ) occur during inspiration. The minimum systolic pressure ( $P_{S-min}$ ) and minimum pulse pressure ( $P_{P-min}$ ) occur during expiration.  $\Delta P_P$  (%) =  $100 \times (P_{P-max} - P_{P-min}) / 0.5 \times [P_{P-max} + P_{P-min}]$ . (From Reference 11, with permission.)

ulizer. With an in vitro model, Hess et al found that, compared with air, powering the nebulizer with heliox decreased both the fraction of the dose and the aerosol's respirable mass.<sup>16</sup> In a pediatric model of mechanical ventilation, albuterol delivery from a metered-dose inhaler (MDI) was higher when the aerosol was delivered with heliox than with air-oxygen mixture.<sup>17</sup>

Goode et al<sup>18</sup> examined nebulizer performance with heliox during mechanical ventilation, using an in vitro model. Delivery of albuterol from an MDI with chamber was greater with heliox than with air-oxygen, and the amount delivered increased with increasing concentration of helium. For both heliox and air-oxygen, the delivery of albuterol was significantly lower when the ventilator circuit was heated and humidified than when the circuit was dry, though in both conditions heliox delivered more albuterol (Fig. 4). When using an MDI with spacer, heliox enhanced the delivery of albuterol through the ventilator circuit so a greater proportion of the drug was delivered distally, and this efficiency increased with increasing concentration of helium (Fig. 5).

On the other hand, heliox decreases nebulizer output efficiency. At a given gas flow, nebulizer aerosol output is higher with oxygen than with heliox (Fig. 6). The best

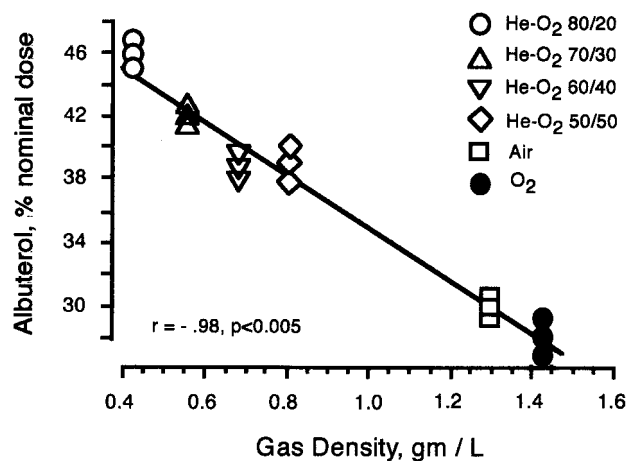


Fig. 4. Gas density versus albuterol delivery (percent of nominal dose) from a metered-dose inhaler to a filter placed at the "bronchi" of the lung model. Albuterol delivery is inversely related to gas density in the ventilator circuit. The highest aerosol delivery occurs with the lowest-density gas, which in these experiments was the mixture of 80% helium and 20% oxygen (He-O<sub>2</sub> 80/20). (From Reference 18, with permission.)

albuterol output is obtained when the nebulizer driving gas is oxygen and the rest of the gas in the circuit is heliox (Fig. 7).

#### Performance of Ventilators With Heliox

Understanding the effects of heliox on ventilator performance requires understanding the principles of valve design and gas flow. Administering heliox during mechanical ventilation requires vigilance and continuous monitoring, because helium can interfere with ventilator functioning and the accuracy of the pneumotachometer. Four studies have examined the effects of heliox on ventilator performance.<sup>19-22</sup>

Tassaux et al<sup>19</sup> evaluated 7 ICU ventilators (Veolar FT, Galileo, Evita 2, Evita 4, Servo 900C, Servo 300, Puritan Bennett 7200) with heliox and a lung model to determine correction factors for the flow difference between heliox and air-oxygen. They studied 78:22 heliox and various mixtures of heliox and oxygen, and they determined heliox's behavior on inspiratory valves and gas mixing. All measurements of flow and volume were made with a density-independent test lung. The actual delivered fraction of inspired oxygen ( $F_{IO_2}$ ) was within 5% of the set  $F_{IO_2}$  with all the ventilators except the 7200, with which the delivered  $F_{IO_2}$  exceeded the set  $F_{IO_2}$  by about 125% (at and below  $F_{IO_2}$  0.6).<sup>19</sup> During volume-controlled ventilation the delivered  $V_T$  was greater than the set  $V_T$  with the Veolar FT, Galileo, Evita 2, Evita 4, and Servo 900C.<sup>19</sup> With the 7200, the delivered  $V_T$  was smaller than the set  $V_T$ , and this relationship was inversely related to the set



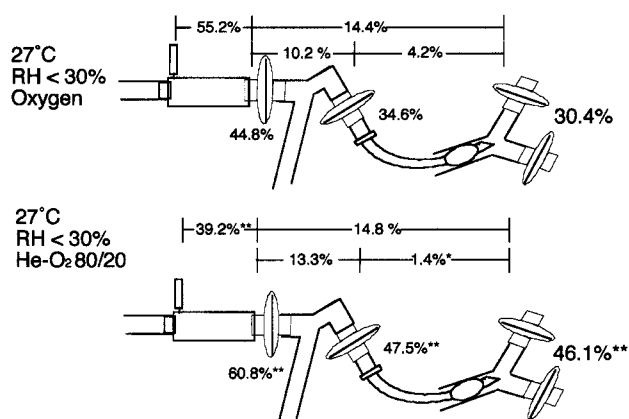


Fig. 5. Drug deposition (percent of nominal dose) of albuterol from a metered-dose inhaler, in the spacer chamber, the ventilator circuit, the endotracheal tube, and on filters on the “bronchi” of the lung model, under dry conditions during controlled mechanical ventilation. RH = relative humidity. He-O<sub>2</sub> = helium-oxygen mixture. (From Reference 18, with permission.)

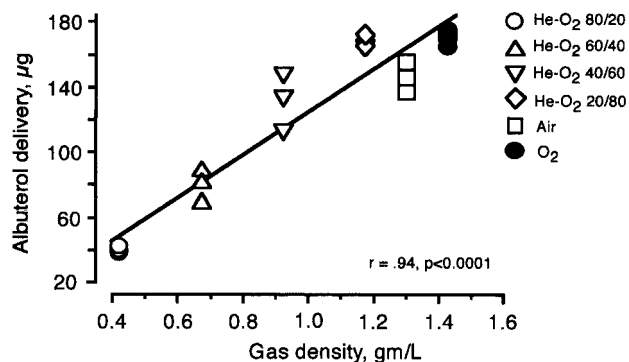


Fig. 6. Albuterol delivery as a function of the density of the gas used to power a small-volume nebulizer at 6 L/min. Albuterol delivery from the nebulizer is positively correlated with gas density ( $r = 0.94$ ,  $p = 0.001$ ). The densest gas (oxygen) gave the greatest nebulizer output. He-O<sub>2</sub> = helium-oxygen mixture. (From Reference 18, with permission.)

F<sub>IO<sub>2</sub></sub>.<sup>19</sup> With the Servo 300, the delivered V<sub>T</sub> was not significantly different from the set V<sub>T</sub>.<sup>19</sup> During pressure-controlled ventilation the delivered V<sub>T</sub> was identical to control measurements with all the ventilators except the 7200, which malfunctioned in that mode. Tassaux et al developed correction factors that can be applied to most ventilators with similar design characteristics.

Oppenheim-Eden et al<sup>20</sup> examined the effects of helium on the performance of 5 ICU ventilators: Siemens 300 and 900C, Puritan Bennett 7200, Evita 4, and Bear 1000. They also studied the functioning of a commercially available Pitot tube sidestream spirometer (Datex CS3 Respiratory Module). All the V<sub>T</sub> measurements were made with a density-independent volume-displacement spirometer. Unlike the study by Tassaux et al<sup>19</sup>, pure helium was con-

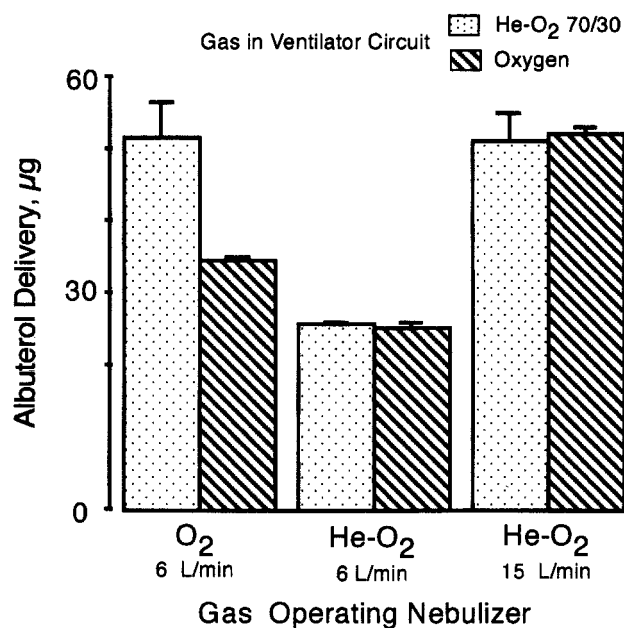


Fig. 7. Drug delivery to filters placed on the “bronchi” of the lung model when the nebulizer was operated with oxygen or heliox, while the ventilator circuit contained heliox (open bars) or oxygen (hatched bars). Albuterol delivery was greatest when the nebulizer was operated with oxygen and the ventilator circuit contained a gas consisting of 70% helium and 30% oxygen (He-O<sub>2</sub>). (From Reference 18, with permission.)

nected to the compressed-air inlet. The 7200 ventilator did not function correctly with helium. The delivered F<sub>IO<sub>2</sub></sub> was lower than the set F<sub>IO<sub>2</sub></sub> with all the other ventilators. Similar to the study by Tassaux et al, the delivered V<sub>T</sub> was unaffected by helium with the Servo 300. With the other 3 ventilators the delivered V<sub>T</sub> was greater than the set V<sub>T</sub> and was dependent on helium concentration. The Pitot tube spirometer consistently underestimated the delivered V<sub>T</sub>, and the underestimation depended on the helium concentration.<sup>20</sup>

Berkenbosch et al<sup>21</sup> examined the effects of heliox on the performance of 4 ventilators that are used with infants and children: Bird VIP, Bird VIP Gold, Servo 300, and Servo 900C. They employed a “bag-in-a-box” spirometer attached to a pulmonary mechanics monitor to obtain density-independent measurements (Fig. 8). Helium consumption was greater with pressure-limited time-cycled ventilation than with volume-controlled ventilation because of the high flow in pressure-controlled ventilation. During both ventilation modes, the Servo 300 was the most efficient in its helium consumption. Using the Servo 300 as the reference value, the helium consumption with the Bird VIP was 8 times higher during volume-controlled ventilation and 17 times higher during pressure-controlled ventilation. With the Servo 900C the helium consumption was 4 times higher during volume-controlled ventilation and 7 times higher

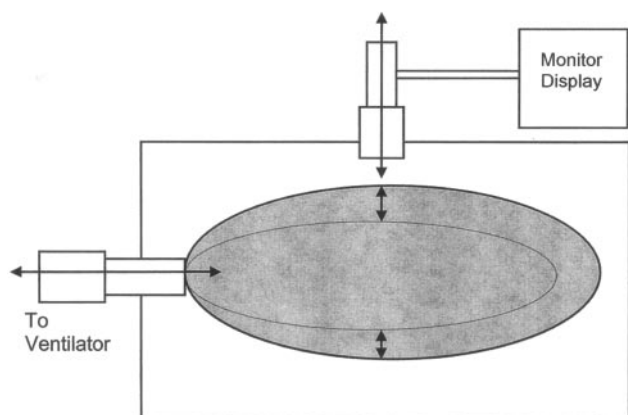


Fig. 8. “Bag-in-a-box” spirometer. The study gas is delivered to the test lung via the ventilator. Expansion of the test lung displaces room air through the top port, which is connected to the pneumotachometer, which is connected to the monitor. (From Reference 21, with permission.)

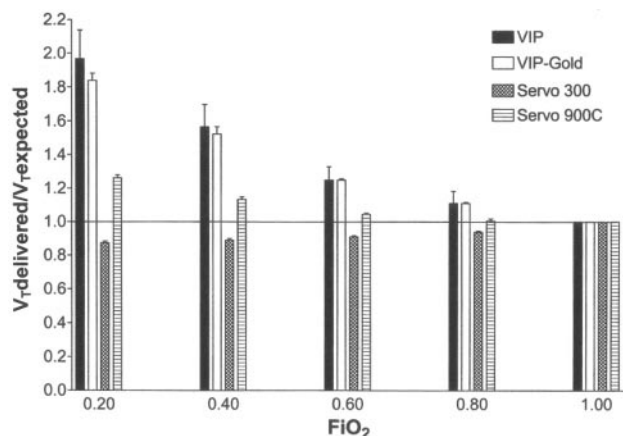


Fig. 9. Effect of helium on actual delivered tidal volume ( $V_T$ ) versus expected  $V_T$  during volume-controlled ventilation with 4 ventilator brands: Bird VIP, Bird VIP Gold, Servo 900C, and Servo 300.  $F_{IO_2}$  = fraction of inspired oxygen (balance helium). (From Reference 21, with permission.)

during pressure-controlled ventilation. With the Bird VIP and Servo 900C, the delivered  $F_{IO_2}$  was less than the set  $F_{IO_2}$ , and the relationship between these variables was nonlinear, with a maximum difference of 9% for both ventilators. Delivered  $F_{IO_2}$  was identical to set  $F_{IO_2}$  with the Servo 300. During volume-controlled ventilation, the delivered  $V_T$  was larger than the set  $V_T$  with the Bird VIP, Bird VIP Gold, and Servo 900C (Fig. 9). With the Servo 300, delivered  $V_T$  was slightly smaller than the set  $V_T$  (Fig. 10). With the Bird VIP, Bird VIP Gold, and Servo 900C, during pressure-controlled ventilation the delivered  $V_T$  increased significantly with increasing concentration of helium, despite the fact that there were no changes in the peak inspiratory pressure limit. The magnitude of the increase was smaller than

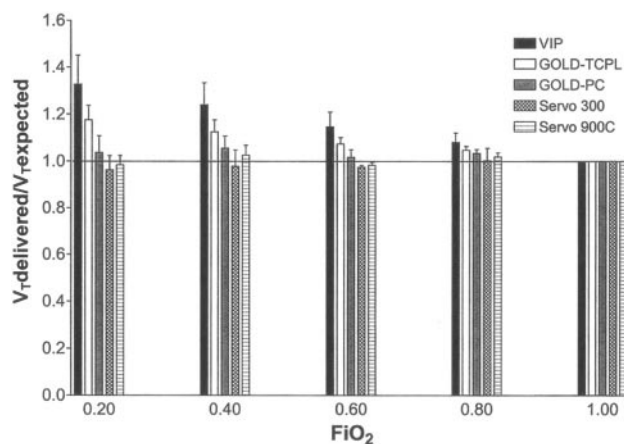


Fig. 10. Effect of helium on actual delivered tidal volume ( $V_T$ ) versus expected  $V_T$  during pressure-controlled ventilation with 4 ventilator brands: Bird VIP, Bird VIP Gold, Servo 900C, and Servo 300. In these experiments, the gas was helium-oxygen mixture.  $F_{IO_2}$  = fraction of inspired oxygen (balance helium). TCPL = time-cycled, pressure-limited ventilation mode. PC = pressure-controlled ventilation mode. (From Reference 21, with permission.)

that during volume-controlled ventilation. With the Servo 300, delivered  $V_T$  was unaffected by  $F_{IO_2}$  during pressure-controlled ventilation.

Brown et al studied the Inspiration and Servo-i ventilators,<sup>22</sup> using a density-independent test lung similar to that in the Tassaux et al study.<sup>19</sup> With the Inspiration the delivered  $V_T$  was always higher than the set  $V_T$ , whereas there was no such difference with the Servo-i. Delivered  $F_{IO_2}$  varied < 5% with both the ventilators. The performance of the exhaled- $V_T$  monitor was quite different between the ventilators. The Inspiration functioned under all the tested conditions, though with heliox the displayed  $V_T$  was always less than the actual  $V_T$ . On the other hand, the expiratory volume monitor in the Servo-i constantly alarmed, displaying a very low value or no value at all.<sup>22</sup>

#### Explanation for the Differences in Performance of Different Ventilators With Heliox

The Veolar FT, Galileo, and Servo 900C each have a single inspiratory valve located downstream from the gas mixer, which is calibrated using a single given  $F_{IO_2}$ . Since there is no built-in system designed to adjust for changes in gas density, the gas flow through the circuit should increase during volume-controlled ventilation with heliox, and the effect will be greater with higher concentrations of helium.<sup>19</sup> The higher gas flow makes the delivered  $V_T$  higher than the set  $V_T$ . The mixing of gases in these ventilators occurs upstream from the inspiratory valve, so the delivery of oxygen is not influenced by the addition of helium.<sup>19</sup> On the other hand, ventilators such as the Evita 2 and Evita 4 are fitted with

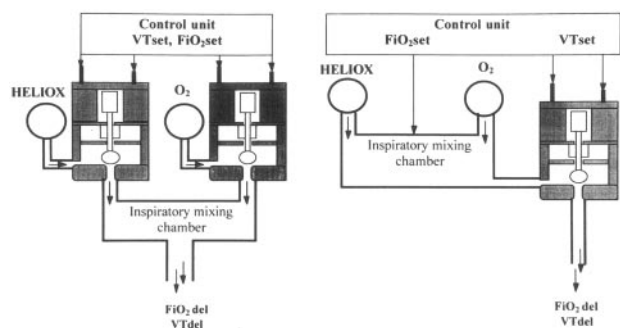


Fig. 11. Inspiratory valve and gas mixing apparatus in the Evita 2, Evita 4, and Servo 300 ventilators (left panel) and in the Veolar FT and Galileo ventilators (right panel). The arrows indicate the gas-flow path.  $V_{T\text{-set}}$  = set tidal volume.  $F_{I_{O_2}\text{-set}}$  = set fraction of inspired oxygen. Heliox = helium-oxygen mixture.  $F_{I_{O_2}\text{-del}}$  = delivered  $F_{I_{O_2}}$ .  $V_{T\text{-del}}$  = delivered tidal volume. (From Reference 19, with permission.)

2 proportional inspiratory valves, one for air, the other for oxygen, and gas mixing occurs downstream from these valves (Fig. 11). This should increase delivered  $V_T$  during volume-controlled ventilation and lower the  $F_{I_{O_2}}$  proportional to the helium concentration.<sup>19</sup> In ventilators such as Evita 4, which has leak compensation, the expiratory flow sensor malfunctions with heliox, and this is interpreted as a gas leak in the circuit, which triggers an increase in inspiratory-valve opening, which further increases the delivered  $V_T$ . With the Servo 900C, gas mixing occurs proximal to the inspiratory valve, so  $F_{I_{O_2}}$  delivery is consistent. On the other hand, the Servo 900C has a scissors valve that is affected by the gas density, so the delivered  $V_T$  differs from the set  $V_T$ . With the Servo 300 and the Servo-i, the air and oxygen modules are separate, each with their own temperature and supply pressure transducer. When helium is introduced into the air inlet, the increased flow results in a higher volume in the chamber, increasing the pressure, which terminates the flow and thus prevents  $V_T$  overshoot. When pure helium is connected to the air inlet, the delivered  $V_T$  is affected more than with heliox.

### Practical Considerations When Using Heliox With Mechanical Ventilation

When using ventilators that do not deliver a consistent  $F_{I_{O_2}}$ , to ensure greater consistency the  $F_{I_{O_2}}$  must be measured close to the patient by devices that are density-independent.

To ensure consistent  $V_T$  delivery there are 2 practical solutions. One is to use a conversion factor derived for each ventilator, as suggested by Tassaux et al,<sup>19</sup> and estimate the delivered  $V_T$  from the set  $V_T$  or the exhaled  $V_T$ . Alternatively, one can measure the  $V_T$  directly at the en-

dotracheal tube, using a density-independent pneumotachometer or one that is calibrated for helium. The CO2SMO pulmonary function monitor is calibrated for helium, and its measured  $V_T$  with heliox is accurate, matching the volume measurements made with a volume-displacement (density-independent) spirometer (unpublished data).

### Heliox During Ventilator Weaning

Diehl et al<sup>23</sup> studied heliox used at the end of the weaning process to determine its effects on work of breathing. They conducted a prospective randomized crossover study with 13 patients with COPD, who were evaluated just before and after extubation. Heliox and air-oxygen were administered sequentially, for 20 min each, in a randomized order, just before extubation. With five of the patients, the study was repeated after extubation. Though heliox did not affect the breathing pattern, it reduced the work of breathing by 21%, mainly by reducing the resistive component of the work of breathing. They also found lower intrinsic PEEP with heliox. All patients who had an improvement in work of breathing had very high initial values. There was a 15% reduction in respiratory rate, a 30% increase in  $V_T$ , a 13% increase in minute ventilation, and a 29% increase in maximum inspiratory flow.

### Summary and Recommendations

Based on the evidence available (which is mostly low-level evidence [class III and IV]), the indications for the use of heliox during mechanical ventilation are:

1. Lower-airway obstruction, especially with hypercarbia
2. Need to enhance aerosol delivery to lung periphery
3. Need to facilitate weaning from mechanical ventilation

Certain ventilators perform relatively well with heliox and are not substantially affected by it. It is preferable to connect the heliox to the air inlet of the ventilator, because this results in more consistent delivery of oxygen and  $V_T$ . When administering heliox, pay close attention and directly monitor the actual  $V_T$  and actual  $F_{I_{O_2}}$ .

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