Case report

High-frequency jet ventilation using a helium–oxygen mixture

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Summary

The physiological basis for the use of helium relates to the relationship described by Poiseuille. During turbulent gas flow, the factors determining the resistance to flow include the density of gas as well as the length and the radius of a tube. While it may not be possible to readily change the latter two, altering the density of the gas is possible by using helium instead of nitrogen. A helium–oxygen combination has been used most commonly to improve air exchange in patients with upper airway obstruction. Anecdotal reports also suggest the beneficial effects of helium during mechanical ventilation in patients with status asthmaticus, hyaline membrane disease, and other pulmonary parenchymal disorders. To date, the clinical reports have utilized helium only with conventional mechanical ventilation. We present a child whose progressive respiratory failure was treated by using high-frequency jet ventilation with a combination of helium and oxygen. The techniques for the delivery of helium and oxygen through the jet ventilator are discussed.

Keywords: helium; ventilation; high-frequency jet

Introduction

Despite improvements in supportive and respiratory care, progressive pulmonary pathology of various aetiologies can end in irreversible respiratory failure and death from hypercarbia and/or hypoxia. Recent options, in addition to conventional ventilatory support, include the high frequency ventilation modalities of jet and oscillatory ventilation (1,2). The purported advantages of the high frequency techniques include the maintenance of mean airway pressure with the provision of adequate oxygenation and ventilation, while limiting the peak inflating pressure and thereby reducing the risks of barotrauma.

Helium was first isolated from atmospheric air in 1895 by Ramsay. Its potential therapeutic effects were first recognized and investigated by Barach in 1935 who advocated its use in the treatment of various obstructive disorders of the trachea, larynx, and bronchi (3,4). The physiological basis for the use

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of previous reports demonstrating its use during HFJV. Gluck *et al.* (11) evaluated helium–oxygen mechanical ventilation in patients with status asthmaticus who did not respond to conventional therapy. All patients were treated with methylprednisolone, albuterol, aminophylline drip and subcutaneous adrenaline. The patients were then selected to receive helium–oxygen if they had a pH less than 7.20, PaO_2 less than 7.8 kPa (60 mmHg), a $PaCO_2$, greater than 65 kPa (50 mmHg), a PIP greater than 75 cm H_2O, and persistent hypercarbia with acidosis after 1 h of conventional therapy. There was a statistically significant ($P < 0.001$) reduction of the $PaCO_2$ within 20 min with a mean reduction of $PaCO_2$ of 5 kPa (38 mmHg) and a mean reduction in PIP of 33 cm H_2O. One of the seven patients was a 16-year-old paediatric patient with preheliox values of: PIP 100 cm H_2O, pH 6.95, $PaCO_2$ 14 kPa (110 mmHg). After 60% helium/40% O_2, the values were: PIP 55 cm H_2O, pH 7.34 and $PaCO_2$ 8.5 kPa (65 mmHg).

Two reports discuss helium use during mechanical ventilation in children (9,12). Elleau *et al.* (9) evaluated the efficacy of helium–oxygen instead of nitrogen–oxygen for mechanical ventilation in premature infants with respiratory distress syndrome. The infants ($n = 31$) were randomized to mechanical ventilation with either helium–oxygen or nitrogen–oxygen. They noted earlier extubation in the infants who received helium–oxygen. Ten of 13 infants who received helium–oxygen underwent extubation at the end of the 8 days compared with five of 14 in the air–oxygen group ($P < 0.05$). The authors also noted an improved $TcPO_2/FiO_2$ ratio ($P = 0.03$) allowing for a lower FiO_2 in the helium–oxygen group. There were also a decreased incidence of bronchopulmonary dysplasia and fewer deaths in the helium–oxygen group (one with helium–oxygen *vs* three with nitrogen–oxygen).

Tatsuno *et al.* (12) described CPAP breathing with helium–oxygen as a bridge from mechanical ventilation to extubation following cardiac surgery in children. The authors' technique included initial ventilation via a CPAP system with 100% oxygen followed by a gradual increase in the helium concentration and a reduction in the rate of respiratory assistance over a 1–2-h period. The patients were left on the helium–oxygen CPAP system for a mean duration of 2.9 days and were then gradually converted to an air–oxygen CPAP system prior to extubation. They noted a significant increase in PaO_2 and a decrease in respiratory rate when breathing helium–oxygen compared to nitrogen–oxygen through the CPAP system.

The beneficial effects of helium are related primarily to its decreased density. During turbulent gas flow, resistance to flow is directly related to the density of the gas. As the density of the gas decreases so does the resistance to airflow. Helium possesses the lowest density of any gas other than hydrogen which is flammable and therefore of no clinical utility. Helium's decreased density may be particularly beneficial during HFJV since minute ventilation is more dependent on tidal volume than during conventional mechanical ventilation (13). During HFJV, the tidal volume delivered to the alveolus is dependent on the frequency and the impedance of the respiratory system. As the frequency and the respiratory impedance increase, CO_2 removal decreases (14). Changes in tracheal tube size, airway resistance, and lung compliance may affect CO_2 more significantly than similar changes during conventional mechanical ventilation. We noted a prompt decrease in our patient's $PaCO_2$ following the use of helium–oxygen instead of nitrogen–oxygen. Helium's effect was readily apparent as we noted a prompt rise in the transcutaneous CO_2 during the 5 min it takes to change the helium tank when it is empty.

Although the primary effects of helium relate to its lower density and thus a decreased resistance to turbulent gas flow, additional effects may also partly explain the beneficial effects of helium. Helium may also increase gas movement by converting turbulent flow to laminar flow. The Reynolds' number is the ratio of kinetic and viscous forces. It predicts whether flow will be laminar or turbulent (turbulent flow occurs with a Reynolds' number greater than 2000). The Reynolds' number is calculated as twice the product of the radius, the average velocity of gas flow, and the density divided by the viscosity. Helium because of its lower density and higher viscosity, when substituted for nitrogen, lowers the Reynolds' number and may convert turbulent to laminar flow. Helium also enhances the diffusion effect on the elimination of carbon dioxide. Carbon dioxide diffuses four to fivefold faster through a mixture of helium–oxygen than nitrogen–oxygen (15). Therefore, for the same partial pressure of carbon of helium relates to the relationship described by Poiseuille. During turbulent gas flow, the factors determining the resistance to flow include the density of gas as well as the length and the radius of the tube. While it may not be possible to readily change the latter two, altering the density of the gas may be possible by using helium instead of nitrogen.

Currently, a helium–oxygen combination is used most commonly to improve air exchange in patients with upper airway obstruction of various aetiologies including infectious and postintubation croup (5–7). Although the majority of the clinical reports outlining the use of helium have included patients with upper airway obstruction, such as subglottic stenosis or oedema, the beneficial effects of helium can also be utilized during mechanical ventilation with obstructive processes more distally along the tracheobronchial tree (8–10). To date, these brief clinical reports have utilized helium only with conventional mechanical ventilation. We present a child whose progressive respiratory failure was treated first with high-frequency jet ventilation (HFJV) followed by high frequency jet ventilation with a combination of helium and oxygen. The techniques for the delivery of helium and oxygen through the jet ventilator are discussed.

Case report

A 12-month-old child with a partial deletion of chromosome 2 presented with a 48-h history of upper respiratory infection symptoms. The rapid antigen test and the culture were positive for respiratory syncytial virus. Progressive respiratory failure related to bronchospasm necessitated tracheal intubation and mechanical ventilation. The bronchospasm was treated with continuous inhaled albuterol and ipratropium bromide, intravenous methylprednisolone and theophylline. Despite aggressive therapy for the bronchospasm, there was a progressive increase in the $PaCO_2$ despite increasing the peak inflating pressure (PIP) to 50 cm H_2O and the rate to 40 $b{\cdot}min^{-1}$. There was no significant improvement with alterations of the respiratory rate, inspiratory time and flow pattern. There was a moderate improvement in oxygenation (increase in PaO_2 of 6.5–7.8 kPa (50 to 60 mmHg) with the addition of nitric oxide in a concentration of 40 parts per million (p.p.m.). Due to the high PIP, it was decided to switch to HFJV in an attempt to limit the risk of barotrauma. With the presence of significant air trapping and hyperinflation related to the bronchospasm, jet ventilation (Life Pulse, Bunnell Inc, Salt Lake City, UT, USA) was chosen over high frequency oscillation. The initial settings on the jet included a mean airway pressure (MAP) of 20 cm H_2O, rate of 520 $b{\cdot}min^{-1}$, PIP 50 cm H_2O, FiO_2 of 0.6, and an inspiratory time of 0.02 s. Nitric oxide was continued at 40 p.p.m. HFJV resulted in a decrease in the $PaCO_2$ from 21 to 11.7 kPa (160 to 90 mmHg). Repeat chest X-ray showed clear lung fields except for right upper lobe atelectasis. To deliver helium through the jet ventilator, the air hose that normally delivers oxygen 21% and nitrogen 79% was adapted to contact to a heliox tank (80% helium and 20% oxygen). Helium, delivered via the adapted air hose, was blended from an 80/20 (80% helium/20% oxygen) tank with oxygen through the blender on the jet ventilator. The fraction of inspired helium was gradually increased from 40% to 60% without a significant decrease in the oxygen saturation or the PaO_2. There was a gradual decline in the $PaCO_2$ from 13 to 7 kPa (100 to 50–60 mmHg). The helium oxygen mixture was continued for 72 h. During this time, the patient developed an increasing alveolar infiltrate compatible with adult respiratory distress syndrome or progressive pneumonia. At this point, there was a significant decrease in the reactive airway component of her disease. Due to her weight, the progressive decrease in respiratory compliance, and the limitations of HFJV, it was not possible to maintain the mean airway pressure (greater than 30 cmH_2O) necessary to provide adequate oxygenation and ventilation. At this time, the patient was switched to high frequency oscillatory ventilation (HFOV). Over the ensuing 4 weeks, the patient had a progressive improvement in her respiratory status, and ventilatory support was slowly weaned. However, bacteraemia with *Candida albicans* developed and resulted in the development of anuric renal failure and progressive cardiovascular dysfunction. The child died 48 h later.

Discussion

Previous studies have suggested the efficacy of helium–oxygen during mechanical ventilation in both adults and children but, to date, we are unaware dioxide, a greater amount of CO_2 would be eliminated per unit of time.

In certain clinical situations, helium has also been shown to improve ventilation-perfusion matching (16). Since bronchoconstriction and altered alveolar compliance lead to areas of low ventilation-perfusion matching, an increased distribution of ventilation to areas of previously low ventilation may result in improved gas exchange. While flow is generally laminar in the more distal parts of the airway, certain pathological conditions may occur which decrease the compliance and increase the resistance of these terminal airways thereby leading to turbulent flow. In this situation, in areas of long time constants (low compliance and high resistance), helium may lead to decreased resistance to gas movement.

Certain logistic problems need to be considered with the delivery of helium–oxygen mixtures during mechanical ventilation. The issues concerning delivery through conventional ventilators have been reviewed elsewhere (17,18). We use 80/20 helium–oxygen, 'H' sized tanks instead of 100% helium tanks to reduce the risk of providing a hypoxic mixture should a mechanical error occur. Although the 100% helium tanks are significantly less expensive, if there were an interruption or problem with the oxygen delivery to the ventilator, it could result in the delivery of 100% helium. The 80/20 tanks are connected to the air intake on the ventricular blender using an air high pressure hose with the adaptor changed to connect from the helium tank to the air inlet.

When switching from oxygen–nitrogen to oxygen–helium, the same ventilator settings are used and the concentration of helium increased as tolerated. Helium concentrations of at least 40–50% are needed to achieve a significant clinical effect. Although this will limit its use in patients with significant oxygen requirements, it is possible that even in patients with an FiO_2 requirement of 70–80%, the small amount of helium may improve distal regional ventilation and improve oxygenation and ventilation to some degree and allow a decrease in the FiO_2 and thereby a secondary increase in the helium concentration.

With the helium–oxygen mixture of 80/20, although the concentration is similar to the 80/20 mixture of nitrogen–oxygen in air, the blender dial that sets the FiO_2 of the ventilator is still not accurate. The blender works by mixing oxygen and the 80/20 mixture of either air (oxygen–nitrogen) or heliox by opening orifices of various sizes. Because of the decreased density of heliox, a greater amount will flow through the orifice thereby diluting out the oxygen to a greater degree. Therefore, the actual FiO_2 will be less than that set on the dial. Monitoring the inspired oxygen concentration with an analyser is essential. Clinical experience suggests that other monitors including endtidal CO_2 devices, transcutaneous CO_2 monitors and pulse oximeters function without difficulty.

Our anecdotal experience suggests that the addition of helium to HFJV may result in better ventilation and oxygenation. The effect is related to the decreased density of helium when compared with nitrogen, thereby improving distal gas exchange. Although the eventual progression of the patient's pulmonary parenchymal disease precluded the continued use of HFJV, helium allowed for effective CO_2 removal and provided time for the resolution of bronchospasm. Once the bronchospasm had resolved, the patient was a better candidate for HFOV. Because of the efficacy of HFOV, we did not find it necessary to use helium with HFOV although similar connections can be made to allow the delivery of helium with HFOV. Preliminary data also suggest that the improved distal gas flow achieved with helium may improve the therapeutic efficacy of agents such as nitric oxide which require delivery into the distal airways (19).

References

1 Clark RH. High frequency ventilation. *J Pediatr* 1994; 124: 661–670.
2 Boros SJ, Mammel MC, Coleman JM *et al.* Neonatal high-frequency jet ventilation: four years' experience. *Pediatrics* 1985; 75: 657–663.
3 Barach AL. The therapeutic use of helium. *JAMA* 1936; 107: 1273–1280.
4 Barach AL. The use of helium as a new therapeutic gas. *Anesth Analg* 1935; 14: 210–213.
5 Skrinskas GJ, Hyland RH, Hutcheon MA. Using helium-oxygen mixtures in the management of acute upper airway obstruction. *Can Med Assoc J* 1983; 128: 555–558.
6 Duncan PG. Efficacy of helium-oxygen mixtures in the management of severe viral and post-intubation croup. *Can Anaesth Soc J* 1979; 26: 206–212.
7 Kemper KJ, Izenberg S, Marvin JA *et al.* Treatment of post-extubation stridor in a pediatric patient with burns: the role of heliox. *J Burn Care Rehab* 1990; 11: 337–339.

8 Gluck EH, Onorato DJ, Castriotta RJ. Helium-oxygen mixtures in intubated patients with status asthmaticus and respiratory acidosis. *Chest* 1990; 98: 693–698.
9 Elleau C, Galperine RI, Guenard H *et al.* Helium-oxygen mixture in respiratory distress syndrome: A double-blind study. *J Pediatr* 1993; 122: 132–136.
10 Tatsuno K, Imai Y, Konno S. Therapeutic use of helium-oxygen mixture in continuous positive airway pressure for early weaning from mechanical ventilation after cardiovascular surgery in infants. *J Thor Cardiovasc Surg* 1976; 72: 119–122.
11 Gluck EH, Onorato DJ, Castriotta RJ. Helium-oxygen mixtures in intubated patients with status asthmaticus and respiratory acidosis. *Chest* 1990; 98: 693–698.
12 Tatsuno K, Imai Y, Konno S. Therapeutic use of helium-oxygen mixture in continuous positive airway pressure for early weaning from mechanical ventilation after cardiovascular surgery in infants. *J Thor Cardiovasc Surg* 1976; 72: 119–122.
14 Fredberg JJ. Summary: pulmonary mechanics during high frequency ventilation. *Acta Anaesthesiol Scand* 1989; 33: 170–171.
15 Christopherson SK, Hlastala MP. Pulmonary gas exchange during altered density gas breathing. *J Appl Physiol* 1982; 52: 221–227.
16 Wood LDM, Bryan AC, Bow SK *et al.* Effect of increased gas density on pulmonary gas exchange in man. *J Appl Physiol* 1976; 41: 206–210.
17 Manthous CA, Morgan S, Pohlman A *et al.* Heliox in the treatment of airflow obstruction: a critical review of the literature. *Respiratory Care* 1997; 42: 1034–1042.
18 Michael JG, Bocklage T, Tobias JD. Helium administration during mechanical ventilation in children with respiratory failure. *J Intensive Care Med* (in press).
19 Petros AJ, Tulloh RMR, Wheatley E. Heli-NO: enhances gas exchange with nitric oxide in helium. *Anesth Analg* 1996; 83: 886–891.

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