Heliox and ventilatory support: What does it mean for the future of infant care?

Helium-oxygen gas mixtures, commonly known as 'Heliox', show promise as a future therapy in a wide range of paediatric respiratory diseases. However, use of Heliox ventilation is not yet widespread in infant care. This article outlines principles and provides guidelines for Heliox-driven mechanical ventilation in neonatology and paediatrics.

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Keywords

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Key points

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1. Heliox is a safe treatment.
2. Heliox, as an adjunct, may enhance mechanical ventilation in infants.
3. Conventional weaning strategies need to be reconsidered in the context of Heliox ventilation.
4. The success or failure of Heliox therapy relies heavily on optimising nursing care.
5. Increasing the helium content of the driving gas mixture is the key to maximising the benefits of Heliox.

In the year 2000, respiratory disease cost the National Health Service over £2.5 billion. Compared to adults, children are more likely to suffer from respiratory illnesses (**TABLE 1**). Mortality is highest in infancy amongst all paediatric age groups (**FIGURE 1**), with respiratory disease being one of the top three causes[3,4]. In the UK in 2004, 3,607 infants died, i.e. >1 in 200 infants[5,6]. It is clear therefore that new and more effective therapies need to be developed to address the growing burden of respiratory disease in infancy.

Administration of a helium-oxygen gas mixture (commonly termed 'Heliox') is one such therapy that has been tried in a wide range of paediatric and neonatal respiratory diseases (**TABLE 2**), with promising results. There have been no documented side effects in the past 35 years of paediatric use.

However, knowledge and awareness of this treatment option is still not widespread, particularly amongst paediatric and neonatal intensive care units, where it may become a life-saving treatment if the current trend of evidence continues. In this article the background principles behind Heliox therapy in intensive care units are reviewed and the use of Heliox-driven mechanical ventilation is discussed, including a proposed guidance for medical management.

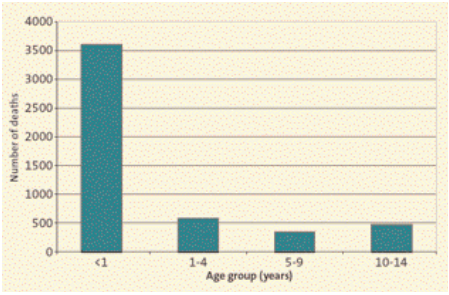

FIGURE 1 Childhood deaths in the UK (2004).

Heliox and its effects on respiratory pathology

Heliox is any gas mixture containing helium (He) and oxygen (O_2). In the UK this is available as a set preparation: Heliox-21, containing 21% O_2 and 79% He. Therefore, in terms of oxygen content, it is comparable to air, which contains 21%

	Population[1]	Respiratory cases[2]	Acute respiratory cases per 1,000 population
Age 0-14	10,890,790	182,874	16.8
Age 15+	48,760,732	612,749	12.6

TABLE 1 Incidence of respiratory disease in the UK, 2004.

Upper airway disorders	Lower airway disorders	Other disorders
Infection	• Asthma	• Tracheomalacia
• Croup	• Cystic fibrosis	• Tracheal stenosis
• Epiglottitis	• Bronchiectasis	• Subglottic stenosis
• Bacterial tracheitis	• Bronchiolitis	• Pneumothorax
Trauma and mass effects	• Pneumonia	
• Foreign body aspiration	• Respiratory distress syndrome	
• Airway tumours	• Bronchopulmonary dysplasia	
• Subglottic injury	• ARDS	
• Post-extubation stridor		

TABLE 2 Reported uses of helium-oxygen gas mixtures in the paediatric respiratory literature.

Gas	Approximate proportions in gas mixture			Density (ρ) (g/L)[7]	Viscosity (η) (micropoises)	Diffusion co-efficient (cm^2/sec)		Thermal conductivity (μcal.cm.sec.°K)[8]
	Oxygen	Nitrogen	Helium			CO_2	O_2	
Air ('Nitrox-21')	21%	79%	0%	1.29	170.8	0.160	0.19	58.0
Heliox-21	21%	0%	79%	0.43	189.5	0.560	0.65	
Oxygen	100%	0%	0%	1.43	192.6	0.138		58.5
Nitrogen	0%	100%	0%	1.25	167.4	0.139		58.0
Helium	0%	0%	100%	0.18	188.7	0.165		352.0

TABLE 3 The physical properties of different gas mixtures.

O_2 and 79% nitrogen. However, due to the helium content, Heliox has a number of important properties (**TABLE 3**).

Viscosity

Heliox has a high kinematic viscosity (ratio of viscosity to density). This promotes laminar flow, which makes it easier to breathe (**FIGURE 2**). The greater the helium content in the helium-oxygen gas mixture, the greater is the potential benefit. Heliox also passes through narrow airways more easily and may reduce the work of breathing by improving O_2 delivery to, and CO_2 removal from, the alveoli. Heliox may also reduce gas trapping and dynamic hyperinflation in obstructive lung disease.

Diffusion of carbon dioxide and oxygen

Heliox has high binary diffusion coefficients for carbon dioxide and oxygen. This means that, in the presence of Heliox breathing, CO_2 and O_2 diffuse at a much more rapid rate which is important for alveolar gas transfer, i.e. Heliox may improve arterial oxygenation and removal of waste gases. Collateral ventilation at the bronchoalveolar level (through Martin's Channels, Canals of Lambert and Pores of Kohn) is dependent on diffusion. Heliox may therefore enhance collateral ventilation and reduce atelectasis[9].

The effects of Heliox on cardio-respiratory physiology have been a source of debate for over 70 years. The effects noted in previous studies are summarised in **TABLE 4** [9-13]. Most of the evidence is Grade 4 or 5. Further high quality physiological studies are therefore needed.

A review of Heliox-driven mechanical ventilation

Heliox-driven mechanical ventilation is not new in paediatrics and neonatology. In 1991 Sauder et al[14] reported the successful use of Heliox ventilation to treat respiratory failure in a two month old infant who had Tetralogy of Fallot,

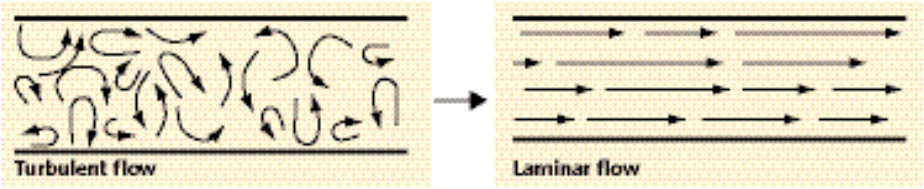

FIGURE 2 The effect of Heliox on gas flow pattern in the airway.

pulmonary atresia and severe tracheal stenosis. This patient had hypercapnoeic respiratory failure unresponsive to high pressures and 100% oxygen with conventional ventilation. Subsequent introduction of Heliox ventilation allowed a gradual reduction in oxygen requirements from 100% down to 30%, a rise in SpO_2 from 80% to 96%, a rise in tidal volume from 66mL to 100mL and an improvement in acid-base with $PaCO_2$ dropping from 115mmHg to 29mmHg and pH improving from 7.03 to 7.55.

Elleau et al[15] provided favourable evidence for the use of Heliox ventilation in neonatal respiratory distress syndrome (RDS), demonstrating a combined reduction in incidence of morbidity (bronchopulmonary dysplasia) and mortality from 71% down to 23%, a reduction in oxygen requirements, a reduction in mean airway pressures and shorter duration of ventilation. This was the first well designed, prospective, double-blind randomised controlled trial of Heliox ventilation in neonates. Elleau's work is supported by the earlier findings of Wolfson et al[16] who showed that spontaneously breathing infants with bronchopulmonary dysplasia had a significantly decreased pulmonary resistance, resistive work of breathing and mechanical power of breathing when breathing Heliox compared to air.

Most authors who have reported a benefit from Heliox ventilation have noted the effect after at least one hour of ventilation. Gross et al[17] presented a small case series of Heliox ventilation in infants with bronchiolitis but failed to show any statistically significant benefit from Heliox treatment. The authors of this study altered the helium-oxygen composition every 15 minutes. This may not have given sufficient time to equilibrate the ventilator driving gases nor for the benefits of the helium to be manifest. Furthermore, the sample size of only 10 patients is likely to have been too small to detect any statistically meaningful differences. Finally, a number of studies[18-21] have demonstrated that the Servo 900C (amongst other ventilators) malfunctions with respect to tidal volume measurements and FiO_2 delivery, in the presence of helium-oxygen gas mixtures. Five out of the 10 patients in the Gross study were under three months of age. Accurately guiding such small tidal volumes and FiO_2 during volume-controlled Heliox ventilation is even more technically difficult, especially when the helium content is being altered every 15 minutes (with resultant changes in

Impact of breathing Heliox on physiology

Cardiovascular effects

- Increased cardiac index
- Decreased right atrial pressure
- Increased pulse pressure
- Decreased pulse pressure variations
- No change in heart rate
- Increased pulmonary blood flow

Respiratory effects

- Reduced work of breathing
- Reduced peak and mean airway pressures
- Reduced intrinsic PEEP
- Improved oxygenation
- Improved carbon dioxide clearance
- Reduced gas trapping and dynamic hyperinflation
- Reduced atelectasis
- Reduced inflammatory cell infiltration

TABLE 4 The cardiorespiratory effects of Heliox.

gas mixture density, flow and ventilator function).

In contrast, Brown et al[22] reported the effective use of Heliox-driven mechanical ventilation in a case of respiratory insufficiency due to bronchiolitis, with a dramatic reduction in CO_2 and acid-base balance, immediately after switching from conventional air/oxygen to Heliox-driven ventilation. Nonetheless, it is interesting to note that, despite the short time intervals of their study, Gross et al reported a significant reduction in intrapulmonary shunting with Heliox ventilation[17] – similar to the findings of Schaeffer et al[23].

Abd-Allah et al[24] showed that Heliox ventilation could reduce peak inspiratory pressures significantly whilst simultaneously achieving improvements in arterial pH and CO_2 clearance, consistent with the findings of several case series[23,25,26] of Heliox ventilation involving children.

Much of the above evidence for Heliox ventilation was derived while using existing ventilators. Conventional ventilators are inaccurate in the presence of Heliox, making patient management difficult. We therefore recommend that Heliox-calibrated ventilators should, preferably, be used for this purpose. There are only two such ventilators currently available in the UK (Inspiration LS, eVent Medical and AVEA, Viasys Healthcare) (**FIGURES 3 & 4**).

It is clear from the above evidence that Heliox shows promise for the advancement of respiratory intensive care. However, to date, no guidelines exist for its use. Therefore, outlined below is a set of principles to guide Heliox ventilation in paediatrics and neonatology, based on the literature evidence to date and the collective experience of Heliox ventilation from a number of institutions across Europe and North America. As more evidence comes to light these guidance notes will, no doubt, need to be reviewed and updated.

FIGURE 3 Inspiration ventilator from eVent Medical.

FIGURE 4 AVEA ventilator from Viasys.

Nursing and practical considerations

Providing Heliox therapy to an infant has proven to be a nursing challenge in several ways. Heliox therapy is a relatively new concept in nursing practice, therefore nurse educators will have a key role to play. Administrating Heliox requires a good understanding of the properties of this gas and how it works. With oxygen therapy the instinctive practice is to increase the oxygen flow or FiO_2 as the patient becomes more hypoxic. In contrast, with Heliox therapy one has to 'balance' the helium *and* oxygen delivery. Indeed, instead of increasing the percentage of oxygen being administered, it is extremely important in Heliox therapy to maximise, when possible, the percentage of helium being given which will make it easier for the oxygen to be 'carried' down with the helium to the different levels of the lung. Therefore, the ultimate objective is to use the minimum amount of oxygen required to maintain the patient's oxygen saturations at a satisfactory level. Experience has shown that this is perhaps the most difficult concept to understand and the greatest change to current nursing practice.

The setup shown in **FIGURE 5** is, in the authors' opinion, the optimum circuit design for driving mechanical ventilation using helium-oxygen gas mixtures. Each component is selected for its particular Heliox-compatibility features. Furthermore, it should be noted that the system shown in **FIGURE 5** is not just suitable for Heliox ventilation but may be used equally well for conventional mechanical ventilation using air-oxygen gas mixtures.

Minimising leaks of Heliox

During mechanical ventilation, it is important to ensure a good seal around the endotracheal tube (ETT). The use of a cuffed ETT is recommended if possible – even for smaller ETT down to size 3.5mm internal diameter. The concern regarding "breathing through a narrow straw" ceases to be valid in the presence of Heliox ventilation as Heliox passes through narrow tubes more easily than conventional gases.

Positioning of the patient

Ideally this should be in the baby's 'position of comfort'. This would be typically at a 30 degree inclination in a

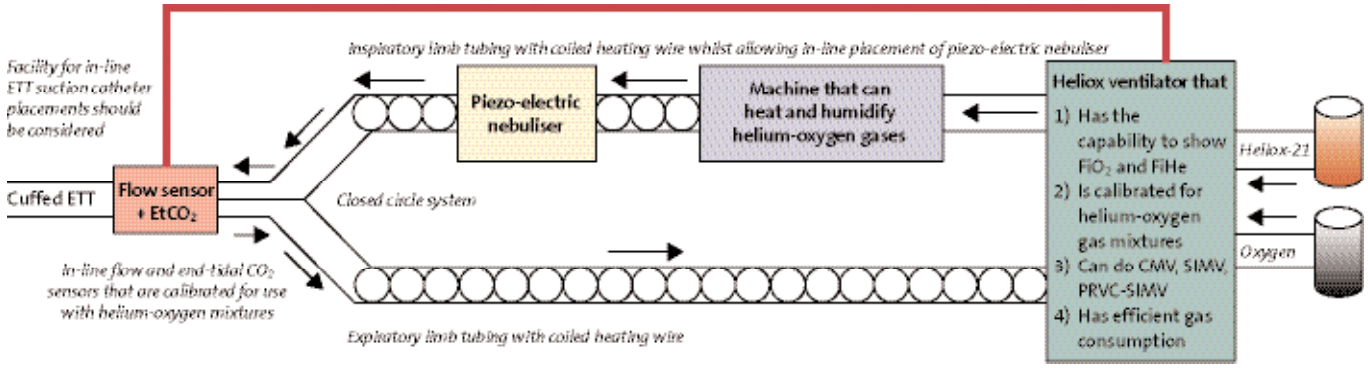

FIGURE 5 Recommended setup for optimum delivery of helium-oxygen mechanical ventilation.

supine or prone position unless there is regional collapse of the lung necessitating 'turning' of the baby (**FIGURE 6**).

Humidification

Davies et al[27] have demonstrated that gases cool rapidly between the point of release from the humidification chamber to the point of entry into the airway. This effect may be greater in the presence of Heliox. It is therefore important that helium-oxygen gas mixtures are well heated and humidified as helium can theoretically carry heat away from surfaces more readily, predisposing to cooling of the patient. This is especially important for neonates and infants. However, as long as the gases are heated and humidified to at least 37°C at the point of entry into the airway, this concern should be satisfactorily addressed.

Ventilating simultaneously with Heliox and anaesthetic gases

Although compatibility of Heliox and volatile anaesthetic gases may be possible[28], there is currently no ventilator that can technically administer both. It is therefore not recommended that Heliox ventilation be utilised if volatile anaesthetic gases need to be used (e.g. intra-operatively).

Condensation in the expiratory limbs of Heliox ventilation circuits

During conventional ventilation the expiratory limb of the ventilation circuit does not contain any healing coil or insulation to avert cooling of expiratory gases. With Heliox ventilation there may be considerable condensate in the expiratory tubing which may potentially affect gas calibrations and ventilator function. Thus the use of insulated and heated expiratory tubing for the ventilation circuit is recommended during Heliox-driven ventilation as well as heating and humidifying the inspired gases.

Calibration of flow sensors and capnographs

Bernoulli's principle states that gas flow in a tube is affected by the density of the gas in that tube. Therefore flow sensors and capnographs are liable to be inaccurate unless specifically calibrated for use with low density helium-oxygen gas mixtures.

Importance of monitoring

Monitoring inspired fractions of oxygen (FiO_2) is as important as helium (FiHe) during Heliox ventilation. Ideally, one should have an FiHe display as well as FiO_2 to help guide therapy. Vater et al[29] showed that there was some benefit in flow characteristics at all levels of FiHe but that the benefit increases with increasing FiHe, with the maximal rise in benefit noted at an FiHe of between 0.4 and 0.6, which is also consistent with the authors' experience.

FIGURE 6 A patient on Heliox ventilation.

Preservation of ventilation circuit integrity

It is important to address this for two reasons. Heliox is relatively more expensive than oxygen and loss of the gas would make the treatment less cost-effective. Furthermore, leakage of the gas could preferentially cause loss of helium from the respiratory tract, thereby diminishing any potential benefit of Heliox. Thus it is important not to 'break' the ventilation circuit during Heliox ventilation. If tracheal toilet is required in-line suction catheters should be used. Nebulisation, if required, may be administered by using an in-line piezoelectric nebuliser (note: some piezoelectric nebulisers cannot nebulise steroids). The same 'in-line' concepts also apply to inhaled nitric oxide administration.

Principles of Heliox-driven respiratory support

Heliox-driven respiratory support should be considered in the following cases:

- Patients who have obstructive airways disease, both upper and lower (e.g. respiratory distress syndrome, asthma, bronchiolitis, croup).
- Patients who have lung atelectasis (e.g. pneumonia, acute lung injury).
- Patients with narrow endotracheal tubes, who may also benefit.

Mode of mechanical ventilation

The bulk of evidence for Heliox-assisted therapy is in the areas of CMV and SIMV modes of ventilation. As there is less evidence for the other modes of conventional mechanical ventilation, the use of only 'CMV' and 'SIMV' is recommended until further evidence becomes available for Heliox ventilation. The ventilators approved for Heliox delivery, that are currently available in the UK, have certain limitations. It is not possible, with current technology, to accurately control tidal volumes of less than 40mL. In such patients, therefore, therapy is directed by pressure-mode and not by volume-mode. A further limitation is that in patients under 0.5kg weight, the tidal volumes become too small to be regulated by Heliox ventilators in either mode.

The mode of ventilation to be used will, therefore, be determined by the desired tidal volume (V_T) which will, in turn, be limited by the weight of the patient. Heliox-driven volume-controlled ventilation is currently not recommended in patients needing V_T < 40mL (i.e. approximately < 6kg). Heliox-driven pressure-controlled ventilation may be used in patients down to premature neonates with ETT size 2.0mm internal diameter and a weight of at least 500 grams and above[30] (**TABLE 5**).

As previously stated it is important to maximise the helium content to gain the greatest potential benefit of Heliox mechanical ventilation. This means that FiO_2

Desired tidal volume (V_T)	Weight limits	Typical patient	Mode of ventilation
< 40mL per breath	< 6kg	Premature neonate Term neonate Young infant (< 3 months)	Pressure-controlled ventilation (CMV or SIMV)
≥ 40mL per breath	≥ 6kg	Older infant (≥ 3 months) Child Adolescent	Volume-controlled ventilation (PRVC-CMV or PRVC-SIMV)

TABLE 5 Selecting the most appropriate mode for Heliox-driven mechanical ventilation.

Weight	< 6kg	≥ 6kg
Mode of ventilation	Pressure control modes (e.g. P-SIMV)	Volume control modes (e.g. PRVC-SIMV)
Fractional inspired oxygen	FiO_2 = 0.4	FiO_2 = 0.4
Tidal volume (VT)	Not applicable (derived from PIP)	10 mL/kg
Peak inspiratory pressures	Whatever minimum PIP is required to achieve SpO_2 of *at least* 93%	Not applicable (derived from tidal volume)
Positive end-expiratory pressure	5 cmH_2O	5 cmH_2O
Inspiratory time	To achieve an I:E ratio of 1:1.5	To achieve an I:E ratio of 1:1.5
Set respiratory rate (RR)	30 breaths per minute (bpm)	30 bpm (infants), 20 bpm (children)
Inspiratory rise phase	Fast	Fast
Exhalation sensitivity	40% of peak inspiratory flow	40% of peak inspiratory flow

NB. Alarm limits have to be adjusted accordingly.

TABLE 6 Recommended initial settings for Heliox ventilation.

should be kept to the minimum required for adequate oxygenation, in order to optimise FiHe. This necessitates greater flexibility and tolerance of oxygen saturations. The aim is to achieve FiHe ≥ 0.6, i.e. $FiO_2 \leq 0.4$ where possible. If a patient is hypoxic, it is preferable to use volume recruitment strategies; increase PEEP, V_T (or PIP in the case of pressure-controlled ventilation) before increasing FiO_2.

Special features of Heliox respiratory support

Success requires patience – When increasing Heliox ventilation settings (PIP, V_T or PEEP), wait at least 15-30 minutes before increasing further, as Heliox-driven lung recruitment may take time. Resist the urge to increase FiO_2 during this time period. Accept SpO_2 as low as 90%.

Effect on V_T and PIP – In volume-controlled ventilation, the higher the FiHe then the lower will be the PIP generated, whilst still achieving the same V_T[26]. In pressure-controlled ventilation, the higher the FiHe then the higher will be the V_T generated, whilst still achieving the same PIP. However, alveolar recruitment may take time (up to one hour) to become fully manifest.

Effect on PEEP – In terms of volume recruitment (V_T) it has been suggested that 1-2 cmH_2O PEEP generated by Heliox may be equivalent to up to 5cmH_2O PEEP generated by air/oxygen mixtures[31]. Therefore when weaning from mechanical ventilation, it is recommended that the PEEP is reduced down to at least 2cmH_2O before extubation.

Increasing PEEP may lead to gas trapping in conventional ventilation. However, this is less likely with Heliox ventilation as the physical properties of the gas reduce the likelihood of gas trapping. Thus increases in Heliox-PEEP should lead to an increase in alveolar recruitment up to a higher "maximum" PEEP before gas trapping starts to become a problem. This indicates Heliox may confer advantage compared to conventional gases when using PEEP levels up to 9cmH_2O[31].

Parameter to wean	Target	Wean only if all the following conditions are met	Weaning strategy
1. FiO_2	≤ 0.4	• SpO_2 > 90% • Patient has been on the current settings for *at least* 10 consecutive minutes	Reduce FiO_2 in steps of 0.05 1. Wait *at least* 10 minutes between each drop in FiO_2 before weaning further 2. If at any point after a drop in FiO_2, the SpO_2 < 90% for 5 mins go back up on the FiO_2 by 0.05
2. PIP	16cmH_2O	Stable for *at least* the past 2 hours on the following settings: • Set PIP > 16 cmH_2O AND • $FiO_2 \leq 0.4$	Reduce the "set PIP" in steps of 1 cmH_2O (note that even one cmH_2O PIP of Heliox is a lot!!) 1. Wait *at least* 2 hours between each drop in PIP 2. If at any point within this waiting period, the SpO_2 < 90% for 5 consecutive minutes go back up on the PIP by +1 cmH_2O. Do NOT increase FiO_2 during this waiting period
3. PEEP	2 cmH_2O	Patient has been on the current settings for *at least* 2 hours • SpO_2 > 90% • $FiO_2 \leq 0.4$	Reduce the PEEP in steps of 1 cmH_2O until you reach the target of 2 cmH_2O 1. Wait *at least* 2 hours between each drop in PEEP 2. If at any point within this waiting period, the SpO_2 < 90% for 5 consecutive minutes increase PEEP by 1 cmH_2O
4. RR	5 bpm	For at least the past 2 hours: • Patient is breathing (i.e. no longer paralysed) • There is adequate depth of spontaneous respiration • Backup respiratory rate (RR) > 5 breaths per minute • PEEP ≤ 5 cmH_2O • Set PIP ≤ 16 cmH_2O • $FiO_2 \leq 0.4$	Reduce the backup respiratory rate in steps of 5-10 breaths per minute (bpm). If the $PaCO_2$ is low, the respiratory rate can be weaned more aggressively. 1. Wait *at least* 2 hours between each drop in backup RR 2. If at any point within this waiting period, the SpO_2 < 90% for 5 consecutive minutes go back up on the backup respiratory rate by 5-10 bpm

TABLE 7 Weaning patients <6kg in weight from Heliox ventilation.

Stepping down – It is suggested that patients be weaned directly from Heliox-driven mechanical ventilation onto either non-invasive Heliox-driven CPAP or, if tolerated, spontaneous inhalation of Heliox. This is because stepping down from Heliox-driven mechanical ventilation into conventional gases would mean simultaneously losing the ongoing benefits of Heliox as well as those of mechanical ventilatory support, thereby risking failure of weaning. Even changing from Heliox ventilation to conventional ventilation could result in a step back for the patient as there is such a significant difference between the two in terms of alveolar recruitment, as demonstrated by Nawab et al[9].

Drop in SpO_2 – As the FiHe increases (and FiO_2 drops), there may be a transient (10-15 minute) drop in SpO_2 (occasionally as low as 85-90%) and a fall in PIP. This may be because it takes time for the higher FiHe to take effect (by increasing alveolar recruitment and oxygen delivery). The drop in SpO_2 is followed by a subsequent rise in SpO_2 and V_T if Heliox ventilation is successful.

Hypocapnoea – Be vigilant for hypocapnoea during Heliox ventilation. Heliox acts quite rapidly, particularly with gas mixtures that have higher helium content. This is because oxygen and CO_2 gas transfers occur 3.5 times faster in the presence of Heliox than with conventional air/oxygen gas mixtures as explained earlier.

Guidance for the medical management of Heliox-driven mechanical ventilation

The following guide is proposed for starting, maintaining and weaning mechanical ventilation driven by helium-oxygen gas mixtures.

Initial settings

Settings for starting Heliox ventilation are shown in **TABLE 6**. Note that as a driving gas, Heliox has less distending pressure and effect on the alveoli than air/oxygen mixtures. Thus a longer inspiratory phase is required compared to conventional mechanical ventilation.

Maintaining Heliox ventilation

Aim to reach the following target parameters prior to discontinuing Heliox-driven mechanical ventilation:

- $SPO_2 \geq 90\%$
- $FiO_2 \leq 0.4$
- PIP = 16 cmH_2O
- Respiratory rate = five breaths per minute

Reducing Heliox ventilation settings

Reduce the ventilation support if there is:

- Adequate oxygenation (i.e. $SpO_2 \geq 90\%$)
- Adequate CO_2 clearance [i.e. $PaCO_2 < 6$ kPa (or in the case of chronic lung disease, back to baseline $PaCO_2$)].

CO_2 clearance is much more rapid in the presence of Heliox due to the high binary diffusion coefficients. The justification for choosing a threshold of $PaCO_2$ of less than 6 kPa in Heliox ventilation is that it theoretically represents a degree of permissive hypercapnoea in conventional air/oxygen ventilation.

The following sequence of stepping down is recommended due to the special nature of Heliox ventilation. However, there should be a ONE HOUR interval before weaning the next parameter.

There is one generic point to remember during the whole weaning sequence. Take advantage of high SpO_2 to reduce FiO_2. Therefore, if at ANY point in this sequence:

- $SpO_2 \geq 95\%$ consistently for 10 minutes, reduce FiO_2 further in 0.05 steps. Wait 10 minutes between each FiO_2 change. If during this 10 minute period $SpO_2 < 90\%$ for at least 5 minutes...go back up by 0.05 FiO_2 step.

Consider discontinuing mechanical ventilation if patients meet the following criteria (**TABLE 7 & 8**):

- There is no hypercapnoea or hypoxia
- Minimal PIP needed to ventilate adequately, i.e. ≤ 16 cmH_2O (patients < 6kg weight) or
  Minimal V_T support needed to ventilate adequately, i.e. ≤ 5mL/kg (patients ≥ 6kg weight)
- Backup respiratory rate (RR) ≤ five breaths per minute
- PEEP ≤ 2 cmH_2O
- $FiO_2 \leq 0.4$

	Target	Wean only if the following conditions are met	Weaning strategy
1. FiO_2	≤ 0.4	• $SpO_2 > 90\%$ • Patient has been on the current settings for *at least* 10 consecutive minutes	Reduce FiO_2 in steps of 0.05 1. Wait *at least* 10 minutes between each drop in FiO_2 before weaning further 2. If at any point after a drop in FiO_2, the $SpO_2 < 90\%$ for 5 mins go back up on the FiO_2 by 0.05
2. V_T	5 mL/kg	Patient has been on the current settings for *at least* one hour • $SpO_2 > 90\%$ • $FiO_2 \leq 0.4$	Reduce the "set V_T" in steps of 1 mL/kg until you reach the target of 5 mL/kg 1. Wait *at least* 1 hour between each drop in V_T 2. If at any point within this waiting period, the $SpO_2 < 90\%$ for 5 consecutive minutes increase V_T by +1 mL/kg. Do NOT increase FiO_2 during this waiting period.
3. PEEP	2 cmH_2O	Patient has been on the current settings for *at least* one hour • $SpO_2 > 90\%$ • $FiO_2 \leq 0.4$	Reduce the PEEP in steps of 1 cmH_2O until you reach the target of 2 cmH_2O 1. Wait *at least* 1 hour between each drop in PEEP 2. If at any point within this waiting period, the $SpO_2 < 90\%$ for 5 consecutive minutes increase PEEP by 1 cmH_2O
4. RR	5 bpm	Patient has been on the current settings for *at least* one hour • $SpO_2 > 90\%$ • $FiO_2 \leq 0.4$	Reduce the backup respiratory rate in steps of 5-10 breaths per minute (bpm) 1. Wait *at least* 1 hour between each drop in backup RR 2. If at any point within this waiting period, the $SpO_2 < 90\%$ for 5 consecutive minutes increase the backup respiratory rate by 5-10 bpm (i.e. to the previous setting)

TABLE 8 Weaning patients ≥6kg in weight from Heliox ventilation.

Management of hypercapnoea

Hypercapnoea, in the context of Heliox ventilation, is defined as:

- $PaCO_2$ > 6kPa (and showing a rising trend) for all paediatric/neonatal cases (except infants with chronic lung disease)
- $PaCO_2$ > 2kPa above their baseline (and showing a rising trend) for infants with chronic lung disease

In patients < 6kg weight ensure optimal lung recruitment using Heliox-PEEP strategies as described above. Once adequate Heliox-PEEP has been achieved, follow a sequence of increasing RR, followed by PIP (once maximum RR has been reached).

Management of hypoxia

Poor oxygenation that requires intervention, in the context of Heliox ventilation, is defined as:

- SpO_2 < 90% (and/or PaO_2 < 8kPa) AND
- FiO_2 > 0.4

Use lung recruitment strategies before increasing FiO_2 > 0.4. Ensure optimal lung recruitment using Heliox-PEEP strategies as described above. Once adequate Heliox-PEEP has been achieved, follow a sequence of increasing PIP (or V_T), followed by RR (once maximum PIP or V_T has been reached).

Recommended maximum settings

The recommended maximum settings for each of the ventilation parameters are:

1. Maximum PEEP = 9cmH_2O
2. Maximum RR = 40 breaths per minute (for infants) or 30 breaths per minute (children)
3. Maximum PIP = 30cmH_2O for infants, 40cmH_2O for children
4. Maximum V_T = 10 mL/kg

If all the above maximum recommended settings have been reached, increase FiO_2 as required in 0.05 steps. Once FiO_2 = 0.6 has been reached, if SpO_2 is still < 90% (PaO_2 < 8kPa), start considering alternative modes of respiratory support in addition to Heliox. In the meantime, FiO_2 can still be increased up to a maximum of 0.9.

CONCLUSIONS

The special physical properties of Heliox have been utilised in the management of obstructive pulmonary disease conditions. These same properties also hold promise when Heliox is used as the driving gas in mechanical ventilation where lung protective and optimal recruitment strategies are employed. Improved CO_2 clearance in obstructive pulmonary disease states is the principle advantage of Heliox ventilation. Optimising the helium content of the driving gas mixtures is the key to maximising the benefits of Heliox ventilation. Conventional weaning strategies must, therefore, be reconsidered in the context of Heliox ventilation.

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