

High-frequency Jet Ventilation with Helium and Oxygen (Heliox) Versus Nitrogen and Oxygen (Nitrox)

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High-frequency jet ventilation (HFJV) is used commonly during microlaryngeal surgery and laryngoscopy. It is the best method for maintaining ventilation and providing good gas exchange with low airway pressure. However, some patients suffering from obesity or decreased lung compliance are poorly ventilated, with resultant hypercarbia and hypoxia.¹ During HFJV, the efficiency of gas exchange depends on the velocity of gas delivery.² Given the physical properties of helium, which has a high kinematic viscosity and a low specific weight, it should provide for better ventilation during HFJV. The purpose of this study is to compare HFJV with nitrox (N₂-O₂) or heliox (He-O₂) on gas exchange in patients with low total pulmonary compliance, during microlaryngeal laser surgery.

MATERIALS AND METHODS

The ventilator used was a solenoid valve actuated jet ventilator (Acutronic® VS600S-LSA). F_{IO₂} was measured with a Beckman oxygen analyzer (Sensormedics® OM11). Tracheal pressure was measured with a Satham pressure transducer (PM 5E), whose frequency response was greater than 5 Hz. The complete response of the entire system (catheter and pressure transducer) was 30 ms. Tracheal pressure was recorded at a chart speed of 2.5 cm · s⁻¹ on a multichannel recorder (U.V. Enertec Schlumberger). Arterial pressure and heart rate were measured and recorded with a non-invasive arterial pressure monitor (Dinamap® 845 Critikon). Hemoglobin saturation (SpO₂) was monitored at the ear with a Ohmeda oximeter (Biox III®) and arterial blood gases were measured with a Corning® 175 analyzer. Neuromuscular blockade was monitored using the re-

sponse of the adductor pollicis muscle to a train-of-four stimulation (Datex® NMT).

Experimental Procedure. Ten patients with brain trauma, whose tracheas were intubated and who had been ventilated for several days and required surgery for tracheal granuloma with CO₂ laser, were studied after informed consent was obtained from the ethics committee of the hospital. Our patients suffered from lung contusion (patients 1, 3, 8, and 9; table 1) and six patients had excess tracheobronchial secretions (patients 1, 3, 4, 8, 9, and 10; table 1). Mean static respiratory compliance was 57 ± 8.5 SD ml · cm H₂O. After cannulating a brachial vein and infusing 500 cc Ringer Lactate, the patients were anesthetized with 6.5 mg · kg⁻¹ pentobarbital and 8 µg · kg⁻¹ fentanyl to prevent an increase of arterial and intracranial pressures during the laryngoscopy. The patients were paralyzed with 0.1 mg · kg⁻¹ vecuronium bromide. Following removal of the endotracheal tube, a 2.5 mm internal diameter and 20 cm long Teflon catheter terminating 5 cm below the vocal cords was inserted through the larynx. A second catheter (2 mm internal diameter) was introduced to the level of the carina to measure tracheal pressure and F_{IO₂}. The patients were then ventilated by HFJV. The respiratory frequency was 100 min⁻¹, the percentage inspiratory time (Ti/Ttot) was 30%, and the driving pressure was regulated to obtain a good chest expansion and SpO₂ higher than 94%. However, the driving pressure could not exceed 3 bars (*i.e.*, 2280 mmHg). The gases used for HFJV were a mixture of oxygen, either in nitrogen (nitrox) or in helium (heliox), with the same F_{IO₂} (40%), both provided in tanks. Composition of the gases was validated with a mass spectrometer. Anesthesia and muscle relaxation were maintained, as needed, by reinjecting 1 mg · kg⁻¹ pentobarbital or 0.02 mg · kg⁻¹ vecuronium bromide, respectively. During laryngoscopy each patient was first ventilated for 15 min with nitrox and then for 15 min with heliox, without changing ventilatory settings. During each period, arterial blood pressure, heart rate, SpO₂, and neuromuscular blockade were monitored. Tracheal pressure, F_{IO₂}, and arterial blood gases were measured at the end of each period. The tracheal pressure transducer, the SpO₂ monitor, and the oxygen analyzer were calibrated before each measurement. Data were compared using the non-parametric Wilcoxon

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Key words: Gases: helium-oxygen; nitrogen-oxygen. Ventilation: gas exchange; high-frequency jet ventilation.

TABLE 1. PaCO_2 and PaO_2 of Ten Patients being Ventilated with HFJV with either Nitrox or Heliox without Changing the Ventilatory Setting (Compliance: $\text{ml} \cdot \text{cm H}_2\text{O}^{-1}$; PaCO_2 and PaO_2 ; mmHg)

Patient	Compliance	Nitrox HFJV			Heliox HFJV		
		FI-O_2	PaCO_2	PaO_2	FI-O_2	PaCO_2	PaO_2
1	45	.39	45	56	.40	30	62
2	60	.37	30	116	.35	27	114
3	53	.39	55	67	.39	41	66
4	65	.35	41	76	.36	34	68
5	55	.40	31	71	.40	26	71
6	62	.39	36	121	.36	27	100
7	50	.34	55	157	.36	50	169
8	62	.36	64	53	.37	41	53
9	74	.34	41	89	.37	33	86
10	50	.36	53	76	.36	46	83
Mean	57	.37	45	88	.37	35	87
Range	45-74	.34-.40	30-64	53-157	.35-.40	27-46	53-169

* $P < 0.01$ compared to nitrox.

matched pairs rank sign test. Linear regression was used to test the degree of correlation between heliox or nitrox and PaCO_2 .

RESULTS

There was no noticeable change in heart rate, blood pressure, or neuromuscular blockade in any patient. Mid-inspiratory tracheal pressure was slightly but significantly increased with heliox ($+1.04 \text{ cm H}_2\text{O}$, $P < .001$). However, the mean tracheal pressure remained low with both nitrox (range 2.2-7.0, mean 4.2 $\text{cm H}_2\text{O}$) and heliox (range 2.5-9.1, mean 5.2 $\text{cm H}_2\text{O}$). In all cases, the tracheal pressure returned to zero during expiration. The PaO_2 did not change significantly (88 mmHg with nitrox and 87 mmHg with heliox) (table 1). The PaCO_2 decreased significantly ($P < 0.01$) with heliox

(table 1). As shown in figure 1, this decrease was larger in patients having a greater PaCO_2 during nitrox ventilation.

DISCUSSION

Nitrox and heliox ventilation sequences were not randomized, because we felt it necessary, from an ethical point of view, to ensure adequate ventilation of the patients first with nitrox HFJV. Furthermore, Babinski *et al.*¹ have shown that a steady state in gas exchange is obtained in less than 10 min with jet ventilation. Therefore, PaCO_2 values obtained after 15 min of nitrox and heliox ventilation are steady-state values. The average increase in the mean tracheal pressure with heliox is slight (about 1 $\text{cm H}_2\text{O}$) but significant. Even with this increase, the mean inspiratory pressure remains acceptable (5.2 $\text{cm H}_2\text{O}$). As discussed below, this change in pressure is due to the increased ventilation with heliox. In all cases, tracheal pressure returns to zero, with no PEEP effect during expiration.

Patients suffering from lung contusion and/or excess tracheobronchial secretions were the most hypercapnic with nitrox, and PaCO_2 decreased with heliox in each patient. Owing to the curvilinear relationship between alveolar ventilation and PaCO_2 , a given increase in alveolar ventilation during heliox HFJV is, in fact, more efficient if the patient is hypercapnic during nitrox HFJV. The increase in alveolar ventilation occurs because flow delivered by the HFJV apparatus, for a given driving pressure setting, is higher with heliox than with nitrox. The injected gas flow was $20.5 \text{ l} \cdot \text{mn}^{-1}$ with nitrox and $33 \text{ l} \cdot \text{mn}^{-1}$ with heliox when the driving pressure was 3 bars (*i.e.*, 2280 mmHg) and $17 \text{ l} \cdot \text{mn}^{-1}$ with nitrox and $24 \text{ l} \cdot \text{mn}^{-1}$ with heliox when the driving pressure was 2 bars (*i.e.*, 1520 mmHg). Because respiratory frequency is kept constant, the increase in ventila-

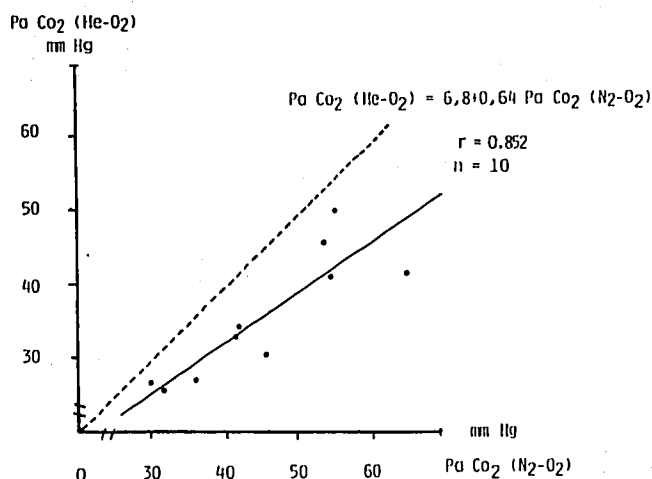


FIG. 1. PaCO_2 during heliox (He-O_2) HFJV versus PaCO_2 during Nitrox ($\text{N}_2\text{-O}_2$) HFJV. Dotted line-identity line; continuous line-linear regression.

tion is achieved by an increase in tidal volume. FI_{O_2} remained close to the oxygen fraction delivered by the apparatus, indicating an absence of air entrainment, which would have decreased the inspired oxygen fraction. This lack of entrainment could be due to the low chest lung compliance of the patients and to the non-axial position of the jet catheter.

Gas transport within the lung results from rather intricate mechanisms that include the diffusive and convective transport of gases and the heterogeneity of the distribution of ventilation from one bronchus to another. Forkert *et al.*³ have shown that in healthy subjects, when low-density gas mixtures are breathed, gas exchange improves when the breathing frequency increases. Robertson *et al.*⁴ reported a better diffusivity of CO_2 in heliox than in air in distal lung units of dogs perfused with inert gases. They point out the fact that heliox shifts the front between convective and diffusive transport towards the trachea during inspiration. This finding is in agreement with the theoretical approach of Paiva.⁵ Thus, gases such as O_2 , which are present in the inspired mixture, have a greater distance to cover from the front to the alveoli during inspiration. CO_2 , which is absent from inspired air, has no such limitation in its transport. Therefore, the effect of breathing heliox during HFJV on arterial oxygenation could be deleterious. In fact, the decrease in Pa_{CO_2} is not correlated with an increase in Pa_{O_2} , which would have been expected if the mechanisms of O_2 and CO_2 transport were the same. Numerous studies have measured blood gases either in healthy subjects, or in patients with chronic bronchitis breathing normoxic heliox or air.⁶⁻⁸ The decreases in Pa_{O_2} reported in these studies are slight, but significant. In dogs artificially ventilated at normal respiratory frequency, Wood *et al.*,⁹ Robertson *et al.*,¹⁰ and Worth *et al.*¹¹ found the same results. Using high frequency oscillation, Mac Evoy *et al.*¹² observed an increase of the alveolo-arterial P_{O_2} difference while breathing He- O_2 . As yet, no study has reported using HFJV with heliox. However, our results are in fairly good agreement with those obtained using other types of artificial or conventional ventilation, the deleterious effect of heliox on oxygen transport probably being compensated for by the increase in ventilation.

In conclusion, heliox HFJV may be useful for patients

in whom CO_2 elimination using nitrox HFJV is impaired. The mechanisms responsible for this improvement include an increase in the flow delivered by the ventilator, and a better washout of CO_2 , due to the diffusive properties of heliox. The deleterious effect of heliox on oxygen transport is probably compensated for by the increased ventilation.

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