Effects of heliox on respiratory management for a patient undergoing laparoscopic bariatric surgery

G. Zheng, N. Gravenstein, T.E. Morey, K. Ben-David, S. Lampotang

Department of Anesthesiology, University of Florida College of Medicine, USA

Abstract

Purpose: The conflict between increased requirement for CO₂ clearance and reduced lung-thorax compliance during laparoscopic bariatric surgery poses a challenge in the ventilation of a bariatric patient’s lungs. With its low density, heliox has been used in respiratory care to decrease airway resistance and airway pressure. We conducted a crossover pilot study to evaluate the effects of heliox on mechanical ventilation during bariatric surgical procedures.

Methods: 11 of 13 consented patients completed the study protocol. Heliox 75/25 was used as a carrier gas during the phase I study, and an air/oxygen mixture with a FiO₂ of 0.3 was used during the phase II study. Data for peak inspiratory pressure, P_{ET}CO₂, and venous blood gas in each phase were compared.

Results: Peak inspiratory pressure increased 14.8% from baseline after the onset of 15 mm Hg pneumoperitoneum. Breathing heliox reduced peak inspiratory pressure 8% from baseline (P = 0.033). No improvement in CO₂ clearance by breathing heliox was noted.

Conclusions: It is unlikely that breathing heliox will confer any clinically significant value to lung management during laparoscopic bariatric procedures.

Key words: heliox, laparoscopic bariatric surgery, peak inspiratory pressure, carbon-dioxide clearance

Introduction

The major issues in ventilation during laparoscopic bariatric surgery are an increased requirement for carbon dioxide (CO₂) clearance, secondary to systemic CO₂ absorption during CO₂ pneumoperitoneum, increased airway pressure as a consequence of reduction in lung-thorax compliance (C_{L,T}) caused by increased abdominal pressure, and, possibly, increase in airways resistance. Obesity is a known cause of decreased C_{L,T}. An obese patient with a body mass index \( \geq 40 \text{ kg/m}^2 \) will be expected to manifest a reduction in lung volumes of up to 20-30%, and requires up to a 56% increase in airway pressure during positive pressure ventilation [1]. Airway caliber is almost linearly proportional to lung volume; thus, when lung volume decreases, the airway caliber also is reduced [2, 3].

Heliox, a low density gas mixture of helium and oxygen, has been used in respiratory care to decrease airway resistance, and, thus, ventilating pressure. Hence, heliox may be an attractive option as a ventilating gas mixture during laparoscopic bariatric surgery. We conducted a pilot study to evaluate the effects of heliox on mechanical ventilation during bariatric surgical procedures.

Methods

After Institutional Review Board (IRB) approval, 13 elective bariatric surgery patients who gave their informed consent were enrolled in the study. Among these were 10 female and 3 male patients; 11 underwent laparoscopic gastric adjustable band placement, and two had laparoscopic Roux-en-Y gastric bypass surgery under general anesthesia. All the patients were
ASA physical status II. The common underlying medical issues were obesity, well-controlled hypertension, diabetes, and smoking. Patients with cardiac, pulmonary, renal, or neuromuscular diseases were excluded from the study. As per our surgical patient selection protocol, all smoking patients required a minimal 6-month smoking cessation and normal arterial blood gas values prior to surgery.

An anesthesia machine (Aestiva/5, GE Healthcare, Madison, WI) with a heliox mode-enabled ventilator (heliox mode is on when a carry gas is heliox) and a heliox flow meter designated and calibrated for a gas mixture of 75% helium and 25% oxygen (heliox 75/25) was used to deliver heliox. Heliox 75/25 was supplied via a central gas supply at 50 ± 5 psig pipeline pressure. Isoflurane was delivered through an Ohmeda Isotec 4 vaporizer (Ohmeda Isotec 4, GE Healthcare, Madison WI). A calibrated sidestream multi-gas analyzer (Capnomac Ultima, Datex-Ohmeda, Madison, WI) was used to monitor the concentrations of inspired and expired gases. Venous blood gas samples were analyzed via an i-STAT portable clinical analyzer with a CG 4+ cartridge (i-STAT Corp. East Windsor, NJ). A single unit analyzer was used to analyze all the samples.

In our institution, the typical amount of time required for a laparoscopic adjustable band procedure is 65 ± 10 minutes; the Roux-en-Y gastric bypass takes about three hours skin to skin. In order to match study time to surgical time, we used a single group crossover study. Each patient was started with a 20-minute ventilation with heliox 75/25 (phase I) immediately after the onset of CO$_2$ pneumoperitoneum, followed by a 20-minute air-oxygen ventilation with a FiO$_2$ of 0.3 (phase II). Both phases were studied during CO$_2$ pneumoperitoneum. A complete washout process eliminated the heliox carry-over effects between the two phases. During the washout process, the fresh gas flow (FGF) was set at 6 L/min of 100% oxygen until a three-minute steady state of 80% or higher end-tidal oxygen concentration was achieved, followed by adding air to the 6 L/min FGF to achieve a FiO$_2$ of 0.3. Once this was accomplished, the FGF was decreased to 2 L/min while keeping the FiO$_2$ at 0.3. This process usually took 10-15 minutes.

All the patients received 1-2 mg of midazolam i.v. for premedication before being transported to the operating room. After premedication, an anesthesia provider closely followed all the patients. Standard ASA monitors were used during the procedure. The anesthesia was induced with an intravenous bolus of propofol 2 mg/kg (ideal body weight, IBW) and 50 µg of fentanyl after pre-oxygenation to achieve an 80% end-tidal oxygen level. Tracheal intubation was facilitated with succinylcholine, 2.4 mg/kg (the succinylcholine dose was adjusted based on 2 mg/kg IBW plus 20%).

After tracheal intubation, all subjects received volume-controlled ventilation, 6 mL/kg (IBW), with ventilation rate titrated to an end-tidal CO$_2$ (P$_{ET}$CO$_2$) of 35-40 mm Hg. The patient’s lungs were ventilated with a FiO$_2$ of 0.3, inspiratory/expiratory ratio (I:E ratio) of 1:2, and PEEP of 5 cm H$_2$O. Peak inspiratory pressure (PIP), P$_{ET}$CO$_2$ and pulse oximetry readings were recorded. A baseline venous blood sample, typically from a hand, was obtained. Patients were then ventilated with heliox 75/25 at a FGF rate (heliox flowmeter setting) of 6 L/min to prime the breathing system (heliox wash-in). When a three-minute steady FiO$_2$ of 0.25 was achieved, the FGF (heliox flowmeter setting) was decreased to 2 L/min. All the preparations were done prior to the onset of CO$_2$ pneumoperitoneum. In order to avoid being potentially misled by nonheliox-calibrated gas monitor readings, venous oxygen partial pressure (PvCO$_2$) was also used as a reference for ventilation adjustment.

Anesthesia was maintained with isoflurane titrated to a target bispectral index (BIS) range of 40-60. Vecuronium was used to assure muscle relaxation with a train-of-four response of one to none per surgical protocol. In addition to isoflurane, a fentanyl bolus was used during the procedure. The doses of fentanyl for a gastric adjust band was 100 µg and for a Roux-en-Y gastric bypass was 250 µg. No other narcotics were administered prior to tracheal extubation. During the surgery, all patients were positioned in a 30-degree head-up position (reverse Trendelenburg on an OPERON D850 surgical table, (BERCHTOLD Corporation, SC, USA) after the onset of pneumoperitoneum. Ventilation settings were then adjusted to allow P$_{ET}$CO$_2$ to increase up to 55 mm Hg throughout the procedure. We were able to achieve this increase in all patients using a tidal volume of 8 mL/kg (IBW), with respiratory rates of 10-14 breaths/min. The study protocol began after reverse Trendelenburg positioning and adjustment of ventilation settings.

For each patient, the study sequence was 20 minutes of breathing heliox 75/25, 10-15 minutes heliox washout by 100% oxygen, followed by 20 minutes of breathing with air/O$_2$ at a FiO$_2$ of 0.3. The ventilation settings were kept identical between the phases. PIP and P$_{ET}$CO$_2$ were recorded after steady state was achieved. A venous blood sample was collected and analyzed at the end of each phase. All the patients were extubated awake after full reversal at the end of surgery.

A person who was not involved in obtaining patient consents and data collection conducted the statistical data analysis.
Statistical Analysis

Demographic data were expressed as mean ± standard deviation. Experimental data were analyzed for normality using the Kolmogorov-Smirnov test with expression, using median values with bar and whiskers plots showing the 25th/75th and 5th/95th percentile values, respectively (SigmaPlot 11.0, Systat Software, Inc., Chicago, IL USA). Inferential statistics were conducted using a one-way analysis of variance (ANOVA) on ranks (Kruskal-Wallis). The factor for the ANOVA examination was the phase of study (baseline, phase I, or phase II). For an overall P value < 0.05, multiple pairwise comparisons were conducted using the Student-Newman-Keuls procedure. A P value < 0.05 was considered statistically significant.

Results

The study protocol was completed in 11 (8 females and 3 males) of 13 patients (n = 11). One patient was withdrawn from the study after conversion to an open procedure, and the other had a laboratory error (i-STAT analyzer failed to read the test cartridge). Nine of 11 patients had a gastric adjustable band procedure, the other two had Roux-en-Y gastric bypass. All patients underwent the study uneventfully. The average age was 38.9 ± 11.0 yrs. The average body mass index was 47.1 ± 10.4 kg/m², and the average duration between injection of propofol for anesthesia induction to phase I data collection for PIP, P\textsubscript{ET}CO\textsubscript{2} and venous blood gas was 42.55 ± 21 minutes. The end-tidal isoflurane concentration to achieve this BIS level ranged from 0.6-1.2%.

The mean ± SD in PIP, P\textsubscript{ET}CO\textsubscript{2}, PvCO\textsubscript{2} and PvO\textsubscript{2} are shown in Table 1. The effects of pneumoperitoneum on PIP and P\textsubscript{ET}CO\textsubscript{2} are shown in Figure 1. For both parameters, patients in Phase II (air/oxygen) demonstrated significantly greater PIP and P\textsubscript{ET}CO\textsubscript{2} compared to baseline or Phase I (heliox) conditions. Likewise, the variations caused by the same conditions on PvO\textsubscript{2} and PvCO\textsubscript{2} are observed in Figure 2, where both Phase I and Phase II differed from the baseline conditions for both gas mixtures; however, no statistically significant difference was noted in these variations between Phase I and Phase II.

![A. Peak Inspiratory Pressure](image)

**Fig. 1.** Variation in peak inspiratory pressure (Panel A) and end-tidal CO\textsubscript{2} (Panel B) before (baseline) and after pneumoperitoneum during ventilation with heliox 75/25 (phase I) or oxygen-air (phase II) gas mixtures in anesthetized, intubated human patients (n = 11) undergoing bariatric surgery. Raw observations for each subject are noted by open circles. Summary data expressed as a bar-whisker plot with the whiskers representing the 5th and 95th percentiles. The solid and dotted horizontal lines within the bars represent the median and mean values, respectively.

| Table 1. The mean ± SD in PIP, P\textsubscript{ET}CO\textsubscript{2}, PvCO\textsubscript{2} and PvO |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Sample size    | PIP (cm H\textsubscript{2}O) | P\textsubscript{ET}CO\textsubscript{2} (mm Hg) | PvCO\textsubscript{2} (mm Hg) | PvO\textsubscript{2} (mm Hg) |
| Baseline value (Mean ± SD) | 11 | 27.00 ± 7.54 | 34.27 ± 3.58 | 46.65 ± 3.44 | 114.73 ± 100 |
| Phase I (Mean ± SD) | 11 | 28.46 ± 4.13 | 35.55 ± 3.70 | 46.45 ± 4.87 | 56.36 ± 13.18 |
| Phase II (Mean ± SD) | 11 | 31.00 ± 4.34 | 41.55 ± 3.98 | 48.15 ± 4.84 | 58.18 ± 18.17 |
Zheng et al.

P < 0.05: *, compared to the baseline condition

Fig. 2. Variation in venous O\textsubscript{2} (P\textsubscript{vO\textsubscript{2}}, Panel A) and venous CO\textsubscript{2} (P\textsubscript{vCO\textsubscript{2}}, Panel B) pressures before (baseline) and after pneumoperitoneum during ventilation with heliox 75/25 (phase I) or oxygen-air (phase II) gas mixtures in anesthetized, intubated human patients (n = 11) undergoing bariatric surgery. Raw observations for each subject are noted by open circles. Summary data expressed as a bar-whisker plot, with the whiskers representing the 5\textsuperscript{th} and 95\textsuperscript{th} percentiles. The solid and dotted horizontal lines within the bars represent the median and mean values, respectively.

Discussion

**Heliox effect on peak inspiratory pressure**

Increased intra-abdominal pressure during pneumoperitoneum is the major contributing factor to elevated airway pressure during laparoscopic bariatric procedures. First, it reduces lung volume due to diaphragm shift. Secondly, increased intra-abdominal pressure restricts diaphragm excursion, which in turn hinders lung expansion. Nguyen et al. [4] reported that a 15 mm Hg pneumoperitoneum during laparoscopic bariatric surgery decreased respiratory compliance by 42% and increased PIP 12%. Dumont et al. [5] found a 17% elevation in PIP in their study. Our results showed that when air/oxygen was used as the carrier gas, PIP increased 14.8% from baseline after a 15 mm Hg pneumoperitoneum. Heliox has been used to improve respiratory system resistance. Helium has 1/7\textsuperscript{th} the density of air. Thus, heliox 75 He/25 O\textsubscript{2} will have a density about a third (38%) that of air, as well as that of an air/O\textsubscript{2} mixture with a FiO\textsubscript{2} of 0.3. The markedly reduced density of heliox 75/25 compared to air/O\textsubscript{2} FiO\textsubscript{2} 0.3 results in a reduction of the Reynolds number. The Reynolds number determines whether flow is laminar or turbulent, and is directly proportional to the density of the gas mixtures used in this study. A lower Reynolds number increases the likelihood of transitioning the flow regimen in the large airways from turbulent to laminar. There is less resistance to flow when flow is laminar compared to when flow is turbulent. When we used heliox75/25, we effectively decreased the Reynolds number to a third of the value for the air/O\textsubscript{2} FiO\textsubscript{2} 0.3 mixture. Thus, the decrease in PIP with heliox 75/25, secondary to decreased flow resistance, is as expected. The clinical value of heliox in short-term airway management has been supported by multiple studies [6-9]. Tassaux et al. [8] reported that intubated and ventilated patients with severe COPD, who were breathing heliox, decreased PIP 17% and plateau pressure 12.5%. Our study revealed a small (8%) but statistically significant (P = 0.033) reduction in PIP when heliox was used as the carrier gas as opposed to FiO\textsubscript{2} 0.3 air/O\textsubscript{2}. The difference between their study and ours is the underlying pulmonary pathophysiology. With COPD, obstruction of small airways causes air trapping and formation of enlarged and damaged alveoli, causing impaired gas exchange. In speculation, when helium is applied to replace air or O\textsubscript{2}, turbulent flow in restricted areas may be replaced by laminar flow in the presence of helium. This will decrease airway resistance and improve flow in those areas; hence, ventilatory efficiency increases. On the other hand, during pneumoperitoneum, decreased lung volume and restriction of lung expansion are the primary underlying problems. The airflow pattern in the presence of reduced lung volume without significant airway restriction (unlike as occurs in COPD), such as pneumoperitoneum, is unclear. The clinical value of an 8% decline in PIP found in our study is unlikely to be clinically relevant in the absence of airway obstructive disease.

**Heliox effect on CO\textsubscript{2} clearance**

Graham’s law states that the diffusion rate of a gas is inversely proportional to the square root of its density. The density of 75/25 heliox is 0.49 g/L; the density of FiO\textsubscript{2} 0.3 air/oxygen is 1.305 g/L. Hess et al. have asserted that CO\textsubscript{2} diffuses faster when its carrier gas is heliox instead of air/O\textsubscript{2} [10]. However, clinically, it is unclear whether the faster diffusion rate will facilitate
CO₂ clearance in controlled ventilation. Attempts to improve CO₂ clearance by breathing heliox have been studied both in the laboratory and clinically [11-14]. The beneficial effect of heliox on CO₂ clearance remains undefined, and improved CO₂ clearance may simply be due to improved alveolar ventilation, unrelated to diffusion. In our study, breathing heliox did not improve CO₂ clearance, as revealed in venous blood gas, although PETCO₂ measurement was significantly lower than PvCO₂ (P < 0.001). Ball et al. [15] reported a 30% decrease in Pplat-CO₂ when helium was increased to 79% in carrier gas. We speculate that the discrepancy between Pplat-CO₂ and PvCO₂ may have been due to under-measurement by our gas analyzer.

Some issues that might be investigated in a future study, but not addressed in this one, include the minimum time to achieve a steady state blood gas level in a bariatric population when one carrier gas replaces another. In our study, a 20-minute cut-off time for each carrier gas was used based on clinical experience. Secondly, our sidestream multi-gas analyzer (Capnomac Utima, Datex-Ohmeda, Madison) was not calibrated with heliox; hence, its accuracy in reading heliox-delivered gases has not been confirmed. Ball et al. [15] investigated three multi-gas analyzers, and found that all three machines had under-measured Pplat-CO₂ in the presence of helium. The proposed mechanism was that “when helium is substituted for diatomic nitrogen, the amount of collision broadening and hence infrared absorption falls, resulting in a lower reading by a capnograph calibrated in nitrogen/oxygen” [15]. Although a correction factor was suggested in their study for each gas monitor, this was not used in our data analysis. Given that the blood gas specimen results were similar, the effectiveness of ventilation was inferred to also be similar.

For the study, all patients were pre-oxygenated to an endpoint of 80% end-tidal oxygen, but there were large baseline PvO₂ variations in the results. This most likely reflects poor oxygen reserve in this population secondary to a lower functional residual capacity. Hence, the baseline PvO₂ values were most likely the result of carry-over effects from pre-oxygenation, induction, and intubation rather than true baseline values of ventilation and oxygenation.

The average time between propofol injection to data collection in phase I was 43 minutes. The non-crossover for phase I of the study brought up the concern of propofol’s carry-over effects in airway resistance. Some studies have shown that propofol has bronchodilator properties [16, 17]. We did not find evidence to support that a single injection dose of propofol 2 mg/kg (IBW) would impose any significant carry-over bronchodilator effect 40 minutes later in addition to the bronchodilation effect from the isoflurane.

**Limitations of the study**

First, this is a nonrandomized pilot study with a small sample size. The nonrandomized protocol may have biased the results. The primary aim of the study was to acquire pilot reference data to discern whether there appeared to be a clinically important effect that merited further study rather than to generalize the results. Another potential limitation is that plateau pressure (Pplat) was not measured. Hence, we are not able to separate changes between Pplat and PIP; such as how the Pplat contributes to the PIP and if heliox has any influence on airways resistance. As the PIP changes were small, we surmised that any Pplat changes would also have been small.

**Conclusions**

In summary, our study revealed that breathing heliox resulted in a small, but statistically significant, reduction in PIP during pneumoperitoneum in bariatric surgery patients compared to breathing an air/O₂ mixture with a FiO₂ of 0.3. It is unlikely that these small effects will confer any clinically significant value to lung management during these procedures.

**Funding**

Support was provided solely through departmental and institutional sources

**Conflict of interest**

Nothing to declare

**Previous presentations**

This report was previously presented, in part, at the 2010 American Society of Anesthesiologists Annual Meeting, San Diego, CA

**References**

Efectele heliox-ului asupra conduitelor ventilatoare la pacientul supus chirurgiei laparoscopice bariatrice

Rezumat

Scope: Conflictul dintre necesitatea eliminării sporiei a bixoxidului de carbon și complianța redusă plămân/torace determină o situație dificilă pe parcursul chirurgiei laparoscopice bariatrice, privind ventilația pulmonară a acestor pacienți. Datorită densității sale scăzute, heliox a fost utilizat în terapia respiratorie cu scopul reducerii rezistenței și presiunii din căile aeriene. Am realizat acest studiu pilot încrucișat pentru a evalua efectele heliox asupra ventilației mecanice pe parcursul procedurilor chirurgicale bariatrice.

Metodă: Unsprezece din cei 13 pacienți care au consimțit să participe, au încheiat protocolul de studiu. Heliox 75/25 a fost utilizat ca gaz de lucru în faza I de studiu și un amestec aer/oxigen cu un FiO₂ de 0,3, pentru faza a doua. Următorii parametri înregistrat au fost comparați între cele două faze de studiu: presiunea maximă inspiratorie, P_{ET}CO₂, precum și presiunea gazelor sangvine din sângele venous.

Rezultate: Presiunea maximă inspiratorie a crescut cu 14,8% raportat la valoarea bazală și după instalarea presiunii de 15 mm Hg pentru pneumoperitoneu (p = 0,033). Nu s-a înregistrat nici o îmbunătățire privind eliminarea CO₂ prin utilizarea heliox-ului.

Concluzii: Este puțin probabil ca heliox să confere o valoare semnificativă clinică în ce privește îngrijirea respiratorie pe parcursul procedurilor chirurgicale bariatrice.

Cuvinte cheie: heliox, chirurgie laparoscopică bariatrică, presiune maximă inspiratorie, eliminare bixoxid de carbon