Effect of Heliox on End-Tidal CO_2 Measurement in Healthy Adults

Jonathan B Waugh PhD RRT RPFT CTTS FAARC, Donna D Gardner MSHP RRT NPS FAARC, and David L Vines MHS RRT FAARC

BACKGROUND: Therapeutic gases and other modalities delivered by inhalation may affect the accuracy of capnographic measurements in 2 ways. First is the specificity of the measurement of CO_2 within the device, and second is the dilution effect of supplemental gases in the ambient air during CO_2 sampling by the device. Our goal was to determine if variables such as inhaled gas composition, gas flows delivered via non-rebreather mask, and mouth open or closed affect measurements of end-tidal CO_2 pressure (P_{ETCO_2}) measured with the Capnostream 20 capnograph. METHODS: We measured P_{ETCO_2} and breathing frequency by capnography in 20 adult normal subjects, with coaching to maintain respiratory frequency between 10 and 20 breaths/min. S_{pO_2} was monitored to detect hypoxemia. A 6 min wash-out period occurred between each 6 min level of testing. RESULTS: A mixed models analysis revealed that the mean ± SD P_{ETCO_2} for all subjects and flows while breathing heliox (37 ± 5 mm Hg) was not different ($P = .50$) from the value while breathing room air (36 ± 5 mm Hg). Repeated measurements with given subjects over 6 min periods of breathing spontaneously 0 L/min, with 10 L/min, and with 15 L/min of either air or heliox showed no difference in P_{ETCO_2} related to flow: $P = .97$ for 0 L/min vs 10 L/min, $P = .87$ for 0 L/min vs 15 L/min. CONCLUSIONS: In normal subjects, P_{ETCO_2} measurements with the Capnostream 20 were not affected by heliox or gas flow at 10 or 15 L/min through a non-rebreathing mask. *Key words: capnography; end-tidal CO_2; heliox.* [Respir Care 2013;58(11):1945–1948. © 2013 Daedalus Enterprises]

Introduction

Capnography provides a means to assess alveolar ventilation, the integrity of the airway, and ventilatory function, by measuring the partial pressure of exhaled carbon dioxide (P_{ETCO_2}) throughout the breathing cycle. CO_2, as a product of cellular metabolism, is carried in deoxygenated blood to pulmonary capillaries, where CO_2 diffuses into the alveolar space for exhalation while oxygen diffuses into the blood, as a function of the partial pressure difference across the alveolar-capillary membrane of each gas. In addition to ventilation and gas exchange, changes in perfusion affect the relationship between arterial CO_2 and P_{ETCO_2} (this effect is minimized in healthy subjects).

A variety of inspired gases (eg, oxygen, helium, nitrous oxide) can affect the accuracy of capnography devices.[1-3] Oxygen can be mixed with helium to enhance its delivery to the alveoli in some cases of partial airway obstruction. Helium is a nontoxic, biologically inert gas of low molecular weight, and has no bronchodilating or anti-inflammatory properties.[4,5] The low density of helium allows it to pass through the airways with less turbulence, thereby reducing the work of breathing in patients with severe airway obstruction. The high diffusion coefficient of helium allows CO_2 to diffuse more rapidly than through air or oxygen, thereby improving CO_2 elimination from the

Dr Waugh is affiliated with the Respiratory Therapy Program, Center for Teaching and Learning, University of Alabama, Birmingham, Alabama. Ms Gardner is affiliated with the Department of Respiratory Care, School of Health Professions, University of Texas Health Science Center at San Antonio, San Antonio, Texas. Mr Vines is affiliated with the Department of Respiratory Care, College of Health Sciences, Rush University Medical Center, Chicago, Illinois.

Dr Waugh and Mr Vines have disclosed relationships with Oridion Capnography/Covidien. Ms Gardner has disclosed no conflicts of interest.

Correspondence: Jonathan B Waugh PhD RRT RPFT CTTS FAARC, Respiratory Therapy Program, Center for Teaching and Learning, University of Alabama at Birmingham, 1705 University Boulevard, SHPB 443, Birmingham AL 35294-1212. E-mail: waughj@uab.edu.

DOI: 10.4187/respcare.02183

lungs.[6] In addition, elimination of CO_2 is also improved with the lower pressure per unit volume of heliox, due to the lower specific gravity of helium, which also reduces intrinsic PEEP and dynamic and physiologic dead space.

The first therapeutic use of a helium-oxygen mixture was in 1934, by Alvin Barach, to relieve dyspnea in patients with asthma exacerbations.[7] Recent clinical studies have focused on using heliox as the driving gas for nebulizing β_2 agonist bronchodilators, to assess aerosol delivery to the smaller airways.[8] Patients requiring heliox are at risk of ventilatory compromise, so careful monitoring of ventilation during heliox administration is important to detect hypercapnia and hypoxemia due to the limit of oxygen percentage in heliox to not more than 30%.

Monitoring of oxygenation and ventilation included continuous pulse oximetry and capnography, and arterial blood gas analysis. In its Capnostream 20 capnograph, Oridion Capnography (now Covidien, Mansfield, Massachusetts), purports to have a CO_2 sensing technology that is unaffected by heliox and anesthesia gases, and minimal dilution of the CO_2 sample by supplemental gases delivered by the CO_2 sampling line. Our aim was to determine if heliox or different inspired gas flows would affect the accuracy of P_{ETCO_2} measurements by the Capnostream 20, either through sampling dilution or the precision of the technology with heliox via a standard non-rebreather mask, at a therapeutic concentration and flow, in healthy subjects with no ventilation or perfusion abnormalities.

QUICK LOOK

Current knowledge

Capnography can aid in confirming endotracheal tube placement, and in monitoring ventilation and metabolic activity. In spontaneously breathing patients, delivery of therapeutic gases, including oxygen and helium, may impact the accuracy of capnography measurements.

What this paper contributes to our knowledge

In a group of normal subjects the addition of helium at 10–15 L/min did not affect end-tidal carbon dioxide measurements.

Methods

This pilot project used a pre-test and post-test design to determine the effects of various gas flows and heliox through a nonrebreathing mask on P_{ETCO_2} measurements by the Capnostream 20. After obtaining institutional review board approval for this study, 20 healthy subjects were recruited to participate. An institutional-review-board-approved advertisement was posted in the School of Health Professions, in key areas (student and faculty lounges, near elevators, and internal department postings) to recruit healthy subjects, 19–55 y old. After obtaining consent from the healthy adult subjects, normal lung function was measured by spirometry (FEV_1, FVC, and percent-of-predicted FEV_1, using the National Health and Nutrition Examination Survey III predicted normal values). We excluded anyone with an abnormal pulmonary status as indicated by spirometry, a history of lung disease (eg, asthma, cystic fibrosis, interstitial lung disorders, or COPD), an oral temperature of $\geq 37.8°C$, and employees of the Department of Respiratory Care. There was no review of medical charts or contact with any of the subjects' physicians to identify lung disease. All subjects who participated received a gift card worth $25, in compensation for their time.

The subjects were given sequential identification numbers, to remain anonymous. The following baseline subject data were recorded: patient demographics (age, sex, ethnicity), lung health history, spirometry values (EasyOne, ndd Medical Technologies, Andover, Massachusetts), noninvasive measurement of heart rate and S_{pO_2} (Oximax, Nellcor/Puritan Bennett, Pleasanton, California), P_{ETCO_2} and breathing frequency (Capnostream 20), manually measured breathing frequency, and patient temperature (via electronic thermometer). We recorded ambient temperature, humidity, and barometric pressure. The Capnostream 20 monitors were verified to be in calibration by the manufacturer immediately prior to data collection and according to the manufacturer's directions for use. None of the subjects had difficulty breathing or reported feeling uncomfortable.

The following study procedures were followed with each subject. The S_{pO_2} sensor was placed on the subject's finger. A single-patient-use noninvasive oral/nasal CO_2 sampling tube was connected to the capnograph and to the breath-sampling cannula in the nares and over the mouth. Correct placement of the CO_2 sampling cannula was verified via visual inspection by one of the investigators before each 6 min test period. The subject identification number was entered into the capnograph, and electronic data capture of the CO_2 waveform was started, in parallel with manual recording on the case record form by study staff. Baseline (no mask) data were recorded on air room for 6 min. Then a non-rebreather mask was placed on the subject's face and good fit was verified. The test gas (room air or heliox [80% helium, 20% oxygen]) and gas flow (10 L/min or 15 L/min) were provided in a random order, using a randomization table. A heliox regulator with flow gauge was used to control proper helium flow. The subjects were blinded to the gas and flow they received. The gases were hidden behind a curtain to prevent the subjects from seeing what type of gas was being delivered and the set flow. The subjects were required not to talk, and viewed

Table. Bivariate Tests of Mean Differences for Gas Mixture and Supplemental Flow Effects*

	P_{ETCO_2} mean ± SD mm Hg	*P*
Air (all)	36 ± 5	.50 for air vs heliox
Heliox (all levels)	37 ± 5	
No mask (0 L/min)	37 ± 4	
Mask at 10 L/min heliox	36 ± 4	.97 for 0 L/min vs 10 L/min
Mask at 15 L/min heliox	36 ± 5	.87 for 0 L/min vs 15 L/min

* Mixed models used to account for covariance among repeated measurements on a given subject.

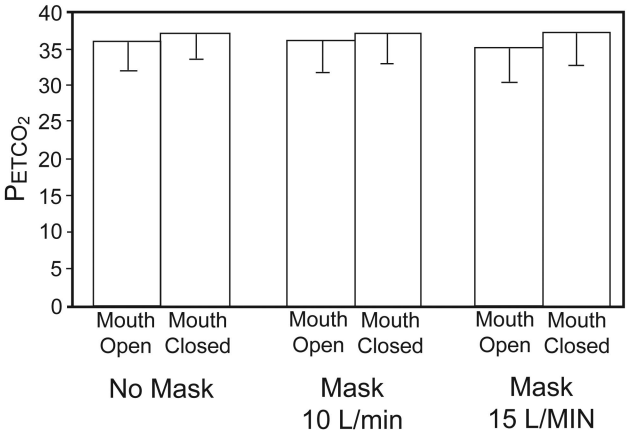

Figure. End-tidal carbon dioxide pressure (P_{ETCO_2}) with the mouth open or closed, with or without mask, with heliox flow of either 10 L/min or 15 L/min. The whisker bars represent the standard deviations estimated with mixed models to account for the covariance among the repeated measurements in a given subject. Bivariate analysis found no significant difference between mouth-open and mouth-closed.

a movie during the 6 min of data capture. The subjects were coached to maintain a normal breathing frequency (12–20 breaths/min) throughout the experiment. The nonrebreather mask was removed for 6 min after each 6 min measurement period, to flush residual effects of the previous gas and flow from the lungs with ambient room air.

The first study question was whether the gas mixture, flow, or mouth-open versus mouth-closed affected the P_{ETCO_2} measurements. Two methods were used to evaluate the differences: bivariate analyses (tests of mean differences in the 5 measured variables of interest for the conditions of gas mixture, flow, and mouth open or closed); and multivariable models (for each of the 5 measured variables a linear mixed model was fitted with the explanatory variables age, sex, time, gas mixture, flow, and mouth open or closed, as well as the interactions gas mixture × flow, gas mixture × mouth open or closed, and flow × mouth open or closed). This included a covariance structure that accounts for statistical dependence among the repeated measurements on a given subject, as well as a lack of homogeneity of variance/covariance between the gas mixture, flow, and mouth open or closed combinations. Statistical significance was based upon an alpha level of .05, and analysis was performed with statistics software (SAS 9.2, SAS Institute, Cary, North Carolina).

Results

This group of 20 healthy adult subjects (75% female) ranged in age from 20–36 y (mean ± SD 25.8 ± 4.7 y) and was comprised of 10% Asian, 5% African-American, 20% white, and 65% identifying as "other." The descriptive statistics for gas mixture effect (air vs 80/20 heliox) and the summary results for the tests of mean differences by gas mixture and flow are given in the Table. The means for each variable are provided with the *P* values to facilitate determination of clinical importance and statistical significance. There were no statistically significant or clinically important differences between the P_{ETCO_2} measurements for all the conditions of gas composition and flow tested. The differences for mouth open versus closed are provided in the Figure. The descriptive and inferential statistics both indicate that the different gas mixtures, flows, and mouth open versus closed produced no significant differences in P_{ETCO_2}.

Discussion

Heliox caused no difference in P_{ETCO_2} and derived breathing frequency measurement by the Capnostream 20 during resting breathing in this group of young adults with normal spirometry. These same measurements were not affected by different flows of heliox or ambient air, compared to breathing with no mask. The tested gas flows are commonly employed in clinical practice and were important to achieve greater confidence in being able to generalize the findings.

Heliox is used in the clinical setting to lower work of breathing in patients with severe obstruction, and could be used in conjunction with capnography, both for intubated and non-intubated patients. Because of the potential for co-incident use of these modalities and the previously described reports of gases affecting earlier capnography technology, it is important to verify the manufacturer's claims that the Capnostream 20 accuracy is unaffected by heliox. The lack of effect is attributed to the proprietary Molecular Correlation Spectroscopy laser-based technology, which produces a precise infrared emission that matches carbon dioxide's absorption spectrum.

Different gas flows were tested to better represent typical clinical variations. The greater the flow, the more

likely the accuracy could be affected, so 2 robust flows were compared to zero gas flow. Likewise, a capnograph must be able to handle the variability of the user's mouth alternating between open and closed. Our results indicate that the oral/nasal sampling cannula was effective at capturing consistent measurements, regardless of whether the user was breathing by nose or mouth.

There are limitations to this study, the first being the fact that the study population was comprised of healthy subjects with no cardiopulmonary disease that could alter dead space or the relationship between arterial and end-tidal CO_2. Second, this was a small pilot study completed in a controlled environment. These findings need to be confirmed in a patient population that requires high gas flows and/or heliox through a non-rebreather mask.

Conclusions

In conclusion, differences in helium concentration, gas flow, and mouth open or closed did not affect the accuracy of P_{ETCO_2} measurements by the Capnostream 20 in healthy subjects. These findings have practice implications for both intubated and non-intubated patients receiving heliox in emergency and critical care settings. Heliox is usually used in patients with high acuity, which further establishes the need to continually monitor them for increasing P_{ETCO_2} and possible respiratory failure. Other critically ill patients receiving oxygen through a non-breather mask also have a need for accurate noninvasive ventilation measurements to guide support and treatment. Further investigation of the Capnostream 20 with high oxygen concentrations and nitrous oxide is merited to determine its susceptibility to these variables.

ACKNOWLEDGMENTS

We would like to thank Luciano Valadez RRT, Manager, Christus Santa Rosa-Northwest Hospital, San Antonio, Texas, and Casey Collette RRT, Director of Respiratory Therapy, Cardiopulmonary Services, St Luke's Baptist Hospital, San Antonio, Texas, for the loan of the heliox regulators for the duration of the study.

REFERENCES

1. Ball JA, Grounds RM. Calibration of three capnographs for use with helium and oxygen gas mixtures. Anaesthesia 2003;58(2):156-160.
2. Raemer DB, Calalang I. Accuracy of end-tidal carbon dioxide tension analyzers. J Clin Monit 1991;7(2):195-208.
3. Carbon dioxide monitors. Health Dev 1986;15(Sep-Oct):255-285.
4. Cheifetz IM, MacIntyre NR. Respiratory controversies in the critical care setting. Conference summary. Respir Care 2007;52(5):636-644.
5. Kim IK, Saville AL, Sikes KL, Corcoran TE. Heliox-driven albuterol nebulization for asthma exacerbations: an overview. Respir Care 2006;51(6):613-618.
6. Hess DR, Fink JB, Venkataraman ST, Kim IK, Myers TR, Tano BD. The history and physics of heliox. Respir Care 2006;51(6):608-612.
7. Barach AL. The therapeutic use of helium. JAMA 1936;107(16): 1273-1280.
8. Fink JB. Opportunities and risks of using heliox in your clinical practice. Respir Care 2006;51(6):651-660.