The authors present the results of a study in which end-tidal carbon dioxide tensions (P\textsubscript{ET\textsubscript{CO}_2}) determined by infrared expired gas analysis were compared to simultaneous arterial carbon dioxide tensions (P\textsubscript{a\textsubscript{CO}_2}) obtained from 15 patients under general anesthesia. Consideration is given to ways to eliminate collision broadening due to the use of N\textsubscript{2}O in calibrating the infrared instrument.

Recently, the utilization of infrared analysis of expired gas to monitor end-tidal carbon dioxide partial pressure (P\textsubscript{ET\textsubscript{CO}_2}) during anesthesia has gained in popularity. In contrast to arterial blood gas analysis, P\textsubscript{ET\textsubscript{CO}_2} analysis is immediate and continuous. Mass spectrometry has also been used to measure P\textsubscript{ET\textsubscript{CO}_2} and has been found to correlate well with arterial carbon dioxide partial pressure (P\textsubscript{a\textsubscript{CO}_2}).

Other expired gases delivered during anesthesia, particularly nitrous oxide (N\textsubscript{2}O), may affect the accuracy of infrared measurement. Because N\textsubscript{2}O is used as part of virtually every general anesthetic, it is of clinical importance to determine what effect it has on the value of infrared-determined P\textsubscript{ET\textsubscript{CO}_2} relative to P\textsubscript{a\textsubscript{CO}_2}.

The study: methods

Fifteen adult patients scheduled for routine nonthoracic surgical procedures gave their informed written consent for a study to determine the effects of N\textsubscript{2}O on infrared CO\textsubscript{2} measurement. There were 10 males, aged 21 to 53 years (mean age 35), and 5 females, aged 30 to 47 years (mean age 36). All subjects were ASA physical status 1 or 2 and free of documented pulmonary disease.

Following induction of general anesthesia and intubation, ventilation was either controlled or assisted. After isoflurane in 60% N\textsubscript{2}O and 40% oxygen was breathed from a partial rebreathing circle carbon dioxide absorption system (total flow 5 L/min) for no less than 30 minutes, a 3 ml heparinized blood sample was obtained anaerobically from the radial artery. Simultaneously, P\textsubscript{ET\textsubscript{CO}_2} was measured with a Cavitron model PM20R infrared carbon dioxide analyzer. A single instrument was used for all studies.

Details of calibration were as follows: After a 30 minute warm up period, the sampling flow was adjusted to 150 ml/min. "Zero" was set using ambient air. A calibrating gas consisting of 5.30% carbon dioxide, 12.63% oxygen and 82.07% nitrogen was then sampled and the span adjusted to 40 mmHg. A barometric pressure of 755 mmHg was assumed in all cases. Calibration and waveform signals were recorded in mmHg on a strip...
chart recorder. Sampling was from the elbow connector at the endotracheal tube, using a 2-meter long, 1.0 mm inner diameter tube of a special perfluorinated plastic (Nafion® by Dupont) which is permeable to water but not gases.

The arterial blood sample was analyzed for pH, \( P_aO_2 \) and \( P_aCO_2 \) within 2 minutes, and the results were corrected to patient temperature as determined by an esophageal thermometer.

After obtaining the first measurement set, the \( N_2O \) was discontinued and anesthesia was maintained with isoflurane in 100% oxygen for at least 10 minutes. The measurements were then repeated in the same manner as with the first set.

Comparison of differences of the paired measurements with and without \( N_2O \) were examined statistically using the Student's T test for paired samples. Differences were considered significant when \( P < .05 \).

**Results**

The \( PCO_2 \) values obtained from simultaneous arterial blood and expired gas samples are displayed graphically in Figure 1. It can be seen that the results obtained in the presence of \( N_2O \) (solid circles) are scattered evenly around the line of identity, while the results with near 100% oxygen (open circles) are consistently below the line.

The mean observed \( PETCO_2 \) with \( N_2O \) was 35.2 (range 23-61) mmHg while the mean \( P_aCO_2 \) was 34.9 (range 23-54) mmHg. Without \( N_2O \) the mean observed \( PETCO_2 \) was 30.9 (range 18-47) mmHg while the \( P_aCO_2 \) was 35.0 (range 22-52) mmHg. The differences between \( PETCO_2 \) and \( P_aCO_2 \) values are summarized in Table 1. A very small and statistically insignificant difference (0.3 mmHg) was observed between the mean values of arterial and end-tidal PCO2 when 60% \( N_2O \) was breathed. However, in the presence of near-100% oxygen, the mean \( PETCO_2 \) was 4.0 mmHg lower than the mean \( P_aCO_2 \), a difference which was highly significant (\( P < .001 \)).

**Discussion**

Infrared analysis of \( CO_2 \) in expired gas is subject to two sources of error in the presence of high concentrations of \( N_2O \). The first is spectral overlap, in which some of the infrared energy is absorbed by \( N_2O \) as well as by \( CO_2 \). Most analyzers now available clinically, including the instrument used in this study, have all but eliminated spectral overlap by the use of optical filtering.2

The second is pressure or collision broadening, in which collisions occurring between molecules of \( CO_2 \) and those of certain other gases in the mixture result in a broadening of the absorption band of \( CO_2 \).8 An erroneously high reading of carbon dioxide is produced, which is related directly to the concentration of both gases.6,6,7

For instance, Kennell et al.7 using seven Godart Capnograph instruments calibrated with \( CO_2 \) in oxygen, found a 7.9% error with 1% \( CO_2 \) and a 12.6% error with 10% \( CO_2 \) in the presence of 80% \( N_2O \). More recently, Russell,8 using two Beckman LB2 analyzers, found similar results. Thus it is clear that an infrared instrument calibrated in the absence of collision broadening can be expected to produce erroneously high readings of \( CO_2 \) in the presence of \( N_2O \).

While oxygen is devoid of collision broadening properties, nitrogen appears to have an effect similar to that of \( N_2O \).6,8 For instance, Ramwell,9 using an instrument calibrated with \( CO_2 \) in ox-

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**Table 1**

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<th>Paired differences ( (PETCO_2 - P_aCO_2) )</th>
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<td><strong>With ( N_2O )</strong></td>
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<td>Mean (mmHg)</td>
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ygen, found a 7.4% error when 5% CO2 was measured in an atmosphere of 95% nitrogen. In the study undertaken for this article, the infrared instrument was calibrated with a gas containing 82.07% nitrogen, thus “correcting” the instrument for much of the collision-broadening effects expected from 60% N2O.

Little difference was found between end-tidal and arterial PCO2 values during N2O anesthesia in the 15 patients studied. In this respect, the findings confirm those of Whitesell et al.1 who, using mass spectrometry, found a mean difference of only 0.8 mmHg between arterial and peak expired PCO2 values in patients with normal lungs. These findings also suggest that the PETCO2 obtained by an appropriately calibrated infrared instrument can be a reliable means of estimating PaCO2 during anesthesia.

On the other hand, the replacement of N2O with oxygen in the breathing gases resulted in observed PETCO2 values consistently lower than the PaCO2, the mean difference being 4 mmHg. The apparent fall in PETCO2 on discontinuation of N2O was in all likelihood due to the loss of collision broadening in an instrument calibrated for its presence. Thus, the collision-broadening effect of N2O, or its absence (depending on how the instrument is calibrated), can be a significant source of error in measuring PETCO2 with the infrared method.

Conclusion

It is obvious from this study that the composition of the calibration gas is important to infrared CO2 analysis. At the very least, the composition should be known so that appropriate correction factors can be determined and applied when the breathing gas is something other than the calibrating gas.

Because N2O is a common component of general anesthesia, and because nitrogen and N2O have similar collision-broadening properties, it would be practical in clinical anesthesia to use a gas with a nitrogen concentration similar to that of air for infrared instrument calibration, as was done in this study. Reasonable accuracy with both N2O and air breathing could then be expected. A negative error of about 4 mmHg in clinical ranges of PCO2 could be expected when oxygen is the breathing gas.

This study also suggests that the use of the anesthetist’s own end-tidal expired breath as a calibrating gas (with an assumed PCO2 of 40 mmHg at sea level), despite the obvious shortcomings, has the benefit of correcting an infrared instrument for collision broadening.

REFERENCES

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