

# Detection of Room Air Contamination of Angiographic CO<sub>2</sub> with Use of a Gas Analyzer

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The purpose of this study was to describe a practical method to detect room air contamination in CO<sub>2</sub> used for angiography. Samples of CO<sub>2</sub> with known room air contamination levels were used in a "bag system" of CO<sub>2</sub> delivery and sampled by a gas analyzer commonly used in anesthesia. Nitrogen levels were reliably detected indicating contamination with as little as 2% air. Oxygen levels were reliably detected, indicating contamination with as little as 5% air. Measured CO<sub>2</sub> values were unreliable with higher-than-true values at all levels except 100%. All clinically important amounts of N<sub>2</sub> and O<sub>2</sub> contamination were readily detected by this practical method.

**Index terms:** Angiography, contrast media • Carbon dioxide • Contrast media

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CARBON dioxide (CO<sub>2</sub>) angiography has found widespread use in patients who have compromised renal function or allergy to iodine. It is a good alternative contrast agent for arteriography, venography, and other applications (1-2). The development of the bag system of CO<sub>2</sub> storage and delivery (Angiodynamics, Queensbury, NY) and careful attention to detail usually provide safe delivery of pure CO<sub>2</sub> (3-4). Still, failures of proper equipment assembly and improper filling of the bag can cause contamination. Although the incidence of complications related to CO<sub>2</sub> angiography is low, serious complications can still be encountered (5-6). In addition, we see ill-defined "side effects" that include a 10%-15% incidence of abdominal cramping and occasional nausea and pain in the involved peripheral vascular beds. Others report widely variable incidences of these phenom-

ena, ranging from 1% to 40% depending on variable side effect definitions and techniques of injection (2,7). It is possible that these, in reality, represent effects of minor degrees of air contamination.

One serious drawback of CO<sub>2</sub> angiography is the inability to easily detect contamination of CO<sub>2</sub> by air. Whereas CO<sub>2</sub> is extremely soluble and safe to use in the vascular tree in moderate amounts, contamination with air, especially the nitrogen in the air, substitutes very insoluble gases, which can produce persistent ischemia and serious complications. Because CO<sub>2</sub> and air are both invisible gases and simple detection methods for air contamination have not been available, meticulous technique has been required to exclude air from the system.

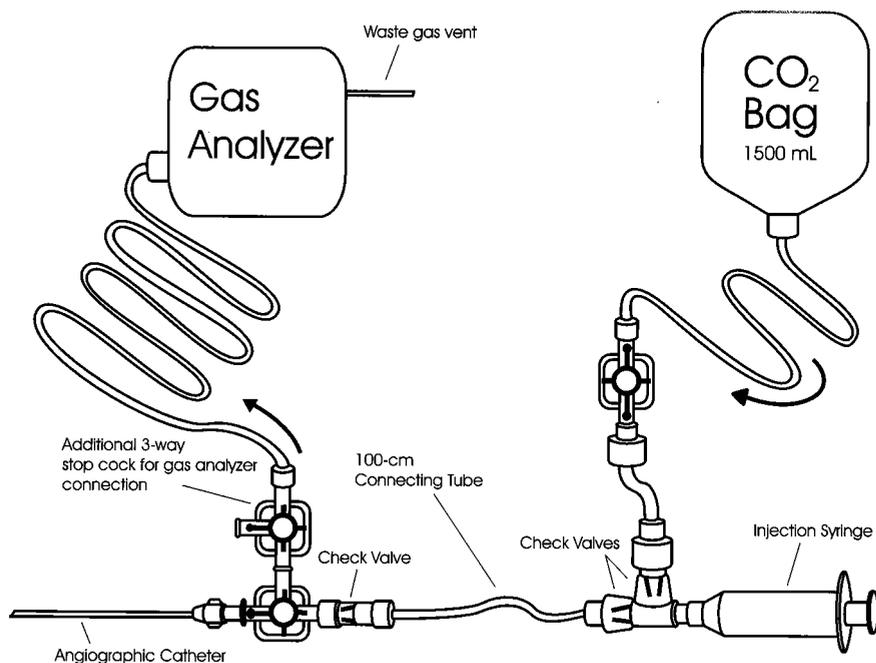
Methods to detect air contamination of CO<sub>2</sub> have been cumbersome and slow, requiring mass spectrometer technology. However, real-time measurement of CO<sub>2</sub>, nitrogen, oxygen, and nitrous oxide can now be accomplished routinely with use of a Raman scattering gas spectrometer, a machine that is often available in anesthesia departments (8). By including the gas analyzer in the circuit, clinically important amounts of air contamination, measured either by nitrogen or oxygen levels, can be detected immediately.

Our specific goals are to demonstrate a practical method of detecting air contamination of CO<sub>2</sub> as used in the clinical practice of angiography and to determine the sensitivity of the current technology when applied outside the designed area of use.

## MATERIALS AND METHODS

Samples of CO<sub>2</sub> with known air contamination levels of 50%, 30%, 20%, 10%, 5%, 2%, and 0% were prepared by measuring 1,500 mL of CO<sub>2</sub> with a Cabot 4000 Electronic Insufflator (Cabot Medical Systems, Stamford, CT) as it was placed in a carefully evacuated "bag system" typically used for CO<sub>2</sub> delivery (Angiofill fluid collection bag; Angiodynamics). Then, a syringe was used to remove the appropriate volume of CO<sub>2</sub> and to introduce the same amount of room air. The bag was inflated to only slightly distend it, but the inability to precisely control pressures when preparing the standard test gases may contribute to errors at larger degrees of air contamination. The contents were mixed by rotating the bag several times before it was hooked to the analyzer (Fig 1). As each test gas was slowly pushed through the system, sample values of CO<sub>2</sub>, N<sub>2</sub>, and O<sub>2</sub> were obtained at 15-second intervals over periods of 1 minute. Then, the line to the analyzer

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**Figure 1.** The gas analyzer is attached to the side port next to the angiographic catheter to sample gases for possible contamination with air. A sample is diverted to the analyzer before angiography (arrows show flow). Accurate measurement is accomplished in a few seconds and with less than 100 mL of gas. Then, flow to the analyzer is turned off. Angiography may begin in the normal manner unless N<sub>2</sub> or O<sub>2</sub> is discovered.

was opened to air for 1 minute and further sampling of air was done in the same manner. The sampling of air and test gas was alternated at 1-minute intervals until 20 values of each gas in the test sample were obtained. A similar number of samples of room air were obtained and tested for each gas. This was repeated for each test gas listed. The sampling was done at the final side port next to the angiographic catheter site or one of the other accesses to the system. Slight pressure had to be applied to the system to overcome the one-way valve resistance.

A standard Raman scatter-type multiple gas analyzer (Rascal) was used for all measurements (Fig 2). Accuracy is stated to be 0.4% volume in a range from 0%–8% volume for CO<sub>2</sub>. Nitrogen accuracy is stated to be 4% volume in a range of 0%–100% volume. Oxygen accuracy is stated to be 2% volume in a range of 0%–40% volume. Time response is stated to range from <250 msec to <500 msec.

These values were compared to the expected values with use of the Spearman rank correlation coefficient, Pear-

son correlation, and Kolmogorov-Smirnoff tests.

## RESULTS

Nitrogen levels were reliably detected indicating contamination with as little as 2% air (mean registered value, 1.3%; Table). The relative error between observed and theoretic values showed a modest correlation with the magnitude of the values (Pearson  $r = .41$ ;  $P = .02$ ).

Oxygen levels were reliably detected, indicating contamination with as little as 5% air (mean registered value, 1%). The relative error showed no correlation with magnitude of the values ( $P = .18$ ).

CO<sub>2</sub> values were uniformly higher than the true values at all levels except 100% ( $P < .0001$ ). The relative error between observed and theoretic values is related to the magnitude of the values (Spearman  $r = .98$ , Pearson  $r = .94$ ;  $P < .0001$ ).

Detection of O<sub>2</sub> and N<sub>2</sub> changes took 3–6 seconds to register precise numerical quantities and showed graphic change almost immediately. Quantifica-

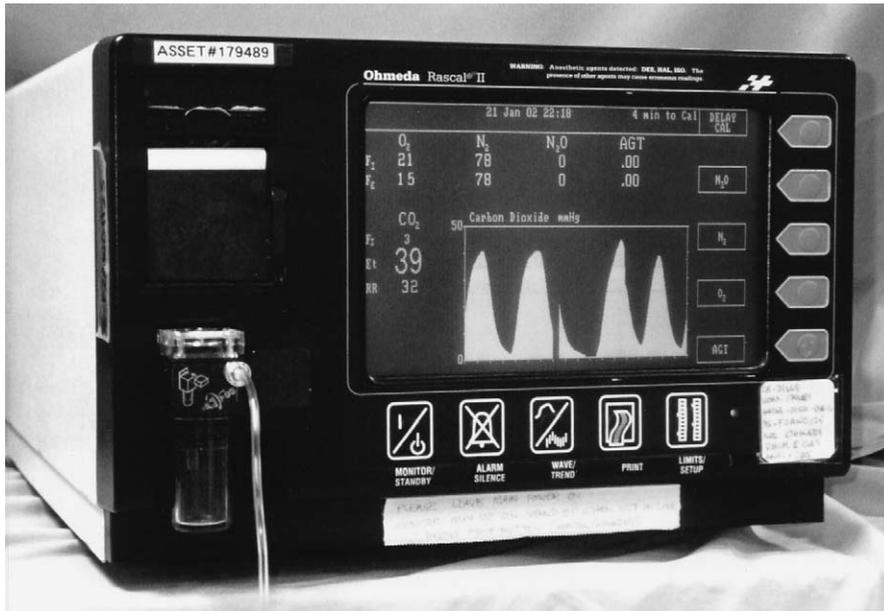
tion of CO<sub>2</sub> changes took 14–22 seconds, well after the almost immediate graphic changes were observed.

## DISCUSSION

Even though CO<sub>2</sub> has been widely used and is usually thought to be a safe contrast agent, occasional reports of complications are presented in the literature (2,5–7). Although it is difficult to tie a particular complication directly to the presence of CO<sub>2</sub>, some of these complications and side effects are thought to be related to vapor lock. Vapor lock, the obstruction of blood flow through a segment of vessel that usually courses through an inverted U-shape configuration which traps the gas because of its buoyancy, is made worse if the gas is insoluble. Although the solubility of CO<sub>2</sub> is many times greater than that of N<sub>2</sub> or O<sub>2</sub>, and therefore produces only transient vapor lock, the contamination of the gas with significant amounts of N<sub>2</sub> and O<sub>2</sub>, the major components of room air, will greatly prolong any vapor lock and increase ischemic symptoms.

Direct real-time measurement of CO<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, and nitrous oxide can now be accomplished routinely with use of a Raman scattering gas spectrometer (8). With a high-intensity argon laser, the gas molecules are momentarily excited to unstable vibrational states. As they return to their normal state, photons of characteristic frequency are emitted for the gases listed herein. Precise measurements are available almost instantly; however, the machines are calibrated for low levels of CO<sub>2</sub> rather than the very high ones needed here. Other more widely used types of gas analyzers are also available, which do not directly measure N<sub>2</sub> but can perform a similar evaluation of O<sub>2</sub> levels. By including the gas analyzer in the circuit, clinically important amounts of air contamination, measured either by N<sub>2</sub> or O<sub>2</sub> levels, can be detected immediately.

Although any air contamination is undesirable, it is unlikely that a very small percentage of air in the injected gas would be symptomatic. It is unclear if even 5%–10% of contamination of a maximum abdominal aortic bolus injection of approximately 40 mL would produce many symptoms. With smaller volumes now in routine use, detection of 5% contamination—1 mL in a 20-mL bolus—is a practical goal. This is easily



**Figure 2.** The gas analyzer is a compact unit (8 in × 13 in × 11 in, weight = 18 lb) that gives graphic and numeric displays of selected gases. Many display formats can be selected. Here, O<sub>2</sub> and N<sub>2</sub> are displayed numerically in percentages and the CO<sub>2</sub> level is displayed both numerically (39 mm Hg instead of a percentage) and graphically (increasing and decreasing instantly during a patient's respirations).

ation does require 200 mL of gas per minute, so it can be in the circuit only intermittently, preferably at the start of a procedure and later if symptoms warrant. Otherwise, the CO<sub>2</sub> bag will soon be exhausted.

This technique can assure at least the absence of common contaminants if not the actual purity of CO<sub>2</sub> used in angiography. It may decrease the incidence of side effects and complications. This should add greatly to the confidence that CO<sub>2</sub> is safe to use in an intravascular location.

In summary, Raman scatter-gas analyzer machines do an excellent job of detecting air contamination of CO<sub>2</sub>. Clinically important amounts of N<sub>2</sub> and O<sub>2</sub> contamination are readily detected by this practical method. The current machine does not directly measure CO<sub>2</sub> well enough to detect small levels of contamination.

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Test Gas (CO <sub>2</sub> %)	Measured CO <sub>2</sub> %	Expected O <sub>2</sub> %	Measured O <sub>2</sub> %	Expected N <sub>2</sub> %	Measured N <sub>1</sub> %
100	100*	0	0*	0	0.14 (0.12, 0.16)
98	100*	0.4	0*	1.5	1.3 (1.28, 1.3)
95	100*	1	1*	3.9	3.9 (3.84, 3.9)
90	100*	2.1	2*	7.8	6 (5.95, 6.06)
80	100*	4.2	3.25 (3.06, 3.44)	15.6	13*
70	99.9 (99.7, 100)	6.3	5*	23.4	18*
50	72.7 (72.2, 73.2)	10.5	8*	39	30.95 (30.78, 31.12)
0 (Air)	0.4 (.39, .45)	21	20.6 (20.55, 20.76)	78	77.4 (77.12, 77.64)

Note.—Mean values are usually well within range of the expected values, except for CO<sub>2</sub>. It is outside its designed operating range of 0%–8% and greatly overestimates the levels. Each category of test gas measurements includes 20 values. Room air values include 140 measurements. Figures in parentheses indicate 95% confidence intervals except where all values were the same (\*) and confidence intervals can not be calculated.

accomplished by this system when measuring N<sub>2</sub> and is also accomplished with O<sub>2</sub> measurement at this level. Only N<sub>2</sub> measurement is sensitive enough to detect as little as 2% contamination. The CO<sub>2</sub> levels measured here are clearly beyond the intended range of this instrument and must not be used as an indicator of pure CO<sub>2</sub>.

This commonly available gas ana-

lyzer system is compatible with the current plastic bag systems of CO<sub>2</sub> delivery for angiography. The machine costs approximately \$12,000 new but is available for less than \$4,000 used. Disposable costs, connecting tubing, etc., are minimal and warmup takes approximately 15 minutes. Testing at the start of an angiography procedure takes approximately 2 minutes. Oper-