Ambulatory measurement of ambient carbon monoxide levels

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ABSTRACT

Background: Measurement of air pollutant levels in the environment is traditionally performed using monitors in fixed locations so that changes over time can be directly compared. Such measurements do not necessarily correlate with the level of exposure to the individual because of distance to the monitoring site and other factors. In the case of carbon monoxide (CO), portable personal monitors are available for industrial use, some of which do not just alarm, but also record measured values.
Objectives: First, it was the purpose of this study to test the feasibility of continuously measuring ambient CO levels in an ambulatory fashion. The second objective was to compare measurements made in a country with significant air pollution to one without to determine the degree to which differences might be observed.
Methods: Ambient CO levels were measured and recorded every 10 minutes during 13 days of travel in Vietnam. A parallel study was performed in the United States for comparison.
Results: Continuous ambient CO levels at an individual level were successfully measured and recorded. Mean ambient CO level throughout Vietnam was 3.5 ± 4.4 ppm, as compared to 0.9 ± 0.8 ppm in the U.S. ($p < 0.001$). In Vietnam, 36 CO measurements (2% of total) were 15 ppm or greater vs. none in the U.S. Higher mean levels, as well as number and magnitude of peaks, were highly associated with proximity to traffic.
Conclusions: Personal exposures to CO can be measured easily over time and may be more relevant to the individual with underlying disease than data from fixed monitoring stations. Such information may prove useful to potential travelers. Additionally, governmental agencies may find ambulatory measurement to be complimentary to data from fixed monitoring stations when attempting to estimate how traditionally collected data relate to exposure of the individual. The technique could also be used for evaluation of vague complaints suggestive of intermittent CO exposure in the home or workplace.

BACKGROUND

Measurement of air pollutant levels in the environment is traditionally performed using monitors in fixed locations in order to compare changes over time. Such measurements do not necessarily correlate with the level of exposure to the individual because of variable distance to the monitoring site, meteorological conditions and other factors. In the case of carbon monoxide (CO), however, portable personal monitors are available for industrial use, some of which are not only alarms, but are also capable of recording measured ambient CO values.

We sought to determine the feasibility of ambulatory ambient CO monitoring during travel in a country with air pollution problems and in another without. If such measurement proved feasible, we also wished to raise awareness of the pollution problem in a polluted country not typically considered by most to have a reputation for air pollution.

China's problem with air pollution and associated inhalational exposure to particulates and toxins, including carbon monoxide, is well publicized [1,2]. Most attribute China's problem to its massive population, use of automobiles without catalytic converters, rapid industrialization and dependence on coal as a major energy source. The government is reported to have banned the use of one-half of the automobiles in the capitol city, Beijing, for five days prior to the start of the 2008 Summer Olympic Games to reduce visible pollution and put forth a good face to the world (3).

Developing countries in Southeast Asia are sometimes assumed to have less of an air pollution problem than China because of less dense population centers and lower levels of industrialization. Recent information,

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largely in the lay media and business literature, suggest that this is not the case. Vietnam, a country considered by many to be predominantly agrarian and largely rural, has recently been reported to have significant air pollution problems, both with regard to particulates and carbon monoxide. A recent report placed Vietnam 123rd of 132 countries in terms of air quality [4].

In Vietnam, monitoring for air pollution is done in cities at fixed locations on the tops of tall buildings by equipment that is apparently frequently in need of repair [5]. Even when operating properly, it has been suggested that the urban levels measured and reported do not relate well to the exposure experienced by an individual at ground level because the major source of pollution is thought to be motor vehicle exhaust.

Faculty and students from a university in Hanoi conducted a pilot study to obtain estimates of personal exposure to particulate matter (PM10) and CO while traveling on four major roads in the city [5]. They carried hand-held monitors and examined the effect of mode of transport, route, rush hour and air conditioning on ambient pollutant levels. They found exposure to both pollutants to be greatest while riding motorbikes and during rush hour. Switching on a car's air conditioning reduced PM10 levels but did not affect CO. When routes traveled had routine rooftop monitoring being performed nearby, CO concentrations at street levels were about 5 parts per million (ppm) higher.

The present study was conducted to measure ambient CO levels continuously throughout travel in Vietnam and again in the United State in an attempt to:

1. determine feasibility of making such measurements;
2. demonstrate that the technique can produce data that easily differentiates the polluted from the non-polluted environment; and
3. attempt to estimate the CO burden that an individual traveler with compromised cardiopulmonary reserve might need to consider when choosing to travel in a polluted environment.

METHODS

One investigator/author traveled from the United States to Vietnam in December 2013. He carried a personal industrial CO gas monitor (Biosystems Toxipro-Single-Sensor Gas Monitor, Model 54-45-01D, Honeywell Inc., Morristown, New Jersey) to continuously measure and record CO levels. This device has a resolution for CO of 1 ppm, a range of 0-999 ppm, and is capable of logging 8,000 data points measured one second apart or longer. Its small size (3.5 ounces) and belt or strap clip allowed it to easily be brought on all activities pursued. The device was gas-calibrated prior to the study and set to log CO measurements every 10 minutes. Simultaneously, the traveler recorded his location and activity at all times in a journal. Upon return to the U.S., the Toxipro monitor was downloaded to a laptop computer via infrared port to an Excel spreadsheet using Biotrak Datalink and Gas Detection Database Software for Windows Version 2.61, designed specifically for this application (Sperian Protection Instrumentation, Middletown, Connecticut).

The 13-day travel itinerary in Vietnam (see Figure 1 for map) included arrival in Hanoi (population 6.56 million; three-day stay) with subsequent bus travel to HaLong Bay, commercial air travel to the coastal city of DaNang (population 926,000; three-day stay), visits to the nearby town of HoiAn (population 120,000), as well as a nearby rural farming community, followed by bus travel to Hue (population 1.09 million; two-day stay).

Commercial air travel was utilized from Hue to Ho Chi Minh City with direct bus transport from the airport to Can Tho (population 1.20 million; two-day stay) on the Mekong River Delta. While there, extensive boat travel throughout the Delta was undertaken. The trip finally included bus travel back to Ho Chi Minh City (population 7.40 million; three-day stay), with one out-of-town excursion to the site of the Chu Chi tunnels.

For comparison, a 13-day protocol was performed in the United States in late January to early February 2014 that attempted to simulate the travel in Vietnam. Monitoring was initiated in Phoenix, Arizona (population 4.19 million; three-day stay), followed by commercial air travel to Seattle, Washington (population 3.50 million; four-day stay), where activity included automobile travel out of the city to a rural island in Puget Sound. Commercial air travel was utilized to return to Phoenix (five-day stay). While in Phoenix, on Day 9 of 13 of the monitoring period, bump testing was performed to insure the detector was operational since most of the readings observed to that point were 0 or 1 ppm. The investigator then flew to Newark, New Jersey, traveled to downtown New York City (population 19.83 million) by train and carried the CO monitor to Times Square on a Friday afternoon at rush hour (arrival 17:30) for one hour of ambulation about the Square.

Figure 1. Map of Vietnam

Source: http://www.lonelyplanet.com/maps/asia/vietnam/map_of_vietnam.jpg
Accessed October 18, 2014.

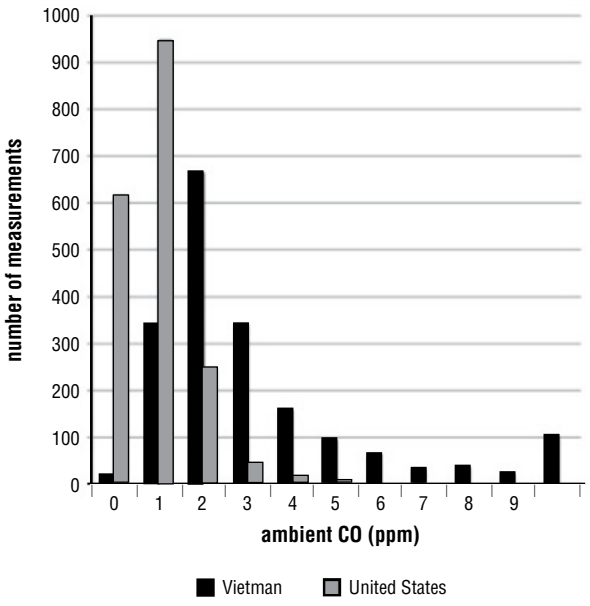
Average ambient CO concentration for both of the 13-day periods were calculated (mean ± SD), as was distribution of individual CO levels measured every 10 minutes. Finally, the written journal was consulted to determine the activity and location for every CO measurement of 15 ppm or greater.

RESULTS

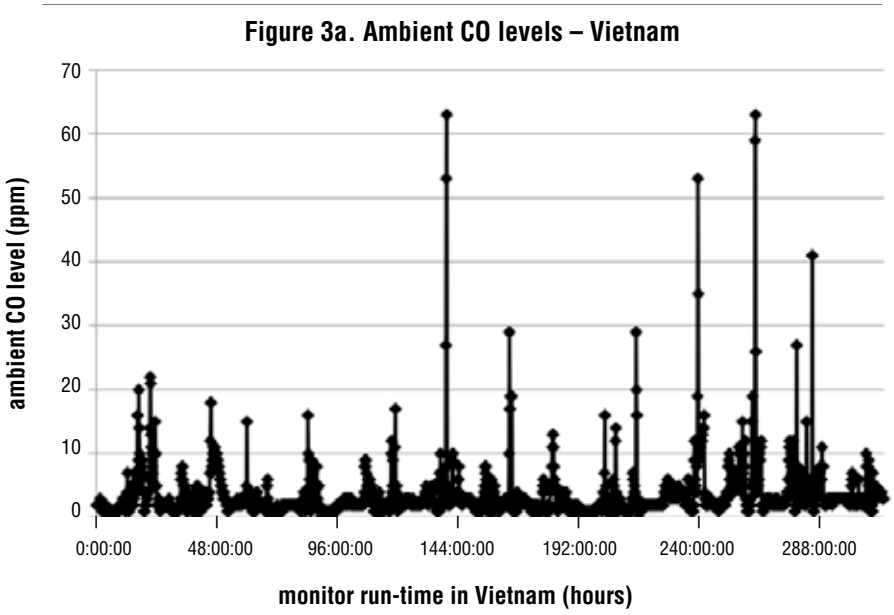
Ambient CO levels in Vietnam measured every 10 minutes over a 13-day trip throughout the country ranged from 0-63 ppm. Of the 1,872 CO measurements, 80% were 1-4 ppm, as seen in Figure 2. Average ambient CO level throughout the country was 3.5 ± 4.4 ppm (mean ± SD). Ambient CO levels in the U.S. over a 13-day trip ranged from 0-10 ppm, with 83% at 0-1 ppm. The average of 1,872 ambient CO measurements throughout the country was 0.9 ± 0.8 ppm ($p < 0.001$ vs. Vietnam average; unpaired two-way t-test).

In Vietnam, 36 CO measurements (2% of total) were 15 ppm or greater (Figure 3a) vs. none in the U.S. (except the one intentional monitor exposure) (Figure 3b). These occurred in Hanoi (n=8), Hoi An (n=2), Hue (n=7), Can Tho (n=4), and Ho Chi Minh City (n=15). None occurred in DaNang, a coastal city with

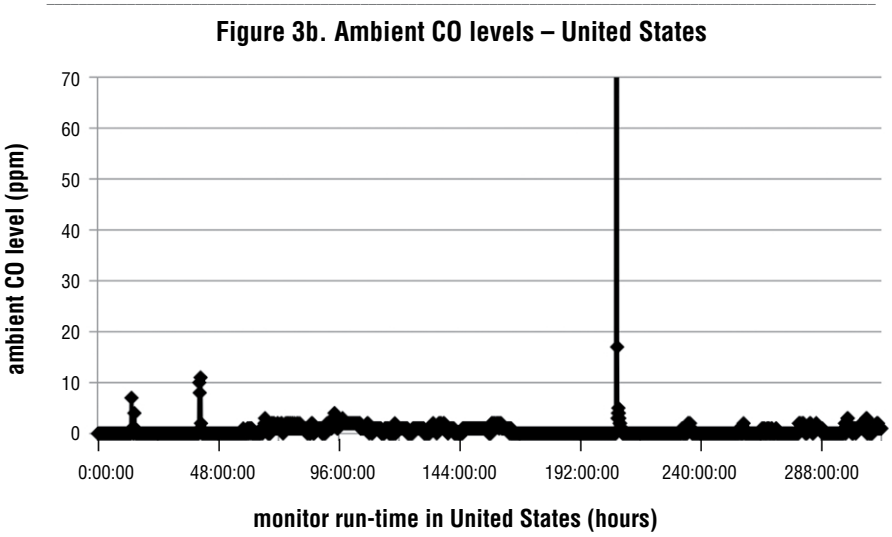
Figure 2. Frequency of total ambient CO levels



Frequency of 1,872 ambient CO levels measured every 10 minutes over 13 days in the country of Vietnam and United States.



Ambient CO levels measured every 10 minutes over 13 days of travel throughout Vietnam (December 2013).



Ambient CO levels measured every 10 minutes over 13 days of travel in the United States (Arizona, Washington State, New Jersey, New York). Spike at approximately 206 hours is an artifact, related to bump testing on Day 9.

strong onshore ocean breezes. Among measurements of 15 ppm or greater, 33 (92%) occurred while walking or riding a bus, taxi, or pedicab in heavy traffic, always dense with motorbikes. The highest level of ambient CO recorded was 63 ppm, once while riding pedicabs through late afternoon motorbike traffic in Hue and once while riding a bus through evening stop-and-go rush hour traffic in Ho Chi Minh City en route to a restaurant.

DISCUSSION

This study demonstrated several interesting findings. Most valuable is the fact that such ambulatory monitoring of an atmospheric pollutant is feasible. This yields the opportunity for government agencies to study and compare a pollutant level experienced by individuals at varying distances from fixed monitoring stations from which the official reported data are generated. This may help validate the applicability of such data to the individual and the population. From

a medical standpoint, a potential application could be evaluation of vague complaints suggestive of intermittent CO exposure in the home or workplace.

Ambient CO levels were consistently higher in Vietnam than in the United States. This was expected from prior reports and is the reason Vietnam was chosen as a comparator. Hanoi has been reported to have air quality that places it among the 10 worst cities in Asia and overall worst for air quality in Southeast Asia [4]. Up to 70 percent of Hanoi's air pollution is blamed on cars and motorbikes. In a city with a population of 6.6 million, there are an estimated 4 million cars and motorbikes, mostly the latter. The motorbikes are typically four-stroke engines with displacements less than 125 cubic centimeters, without catalytic converters. Motorbikes account for about 60% of all vehicular trips and bicycles 30% [5]. During rush hours, Hanoi streets are dense with motorbikes. Visible pollution clouds the air and many riders wear respirator masks. Hanoi's public transit use is among the lowest in Asia [6]. Similar situations exist in most urban centers in Vietnam.

The measurements obtained in the U.S. were also of the magnitude that would be predicted. The first version of the United States Clean Air Act was written by the U.S. Environmental Protection Agency (EPA) in 1970 in an attempt to control the severity of pollution that was common in Los Angeles during the 1960s [7]. The Act set limits for various pollutants and makes states responsible for achieving those standards. It has been very successful. By 1990, improvement in air quality was estimated to be saving 205,000 premature deaths annually, and it is estimated that it will be saving 230,000 lives per year by 2020 [7].

The U.S. Clean Air Act has set air quality standards for six common air pollutants, one of which is CO. The Clean Air Act aims to specify a level of air quality, the attainment and maintenance of which is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of the pollutant in the ambient air [8,9]. Levels are monitored at fixed recording stations throughout the country and the states are responsible for meeting the standards. For CO, eight-hour averages are measured [8].

The EPA's current standard for carbon monoxide in the United States is a maximum of 9 parts per million (ppm) for eight hours and 35 ppm for one hour, neither to be exceeded more than once per year in a locality [8,9]. The country has done a good job of achieving this standard. The second highest eight-hour CO concentration averaged across 114 monitoring sites nationwide in 2009 was 80 percent lower than that for 1980, and is the lowest level recorded during the past 30 years [11]. In addition, of the 114 sites used to determine this trend (out of 332 total monitoring sites that were operating in 2009), the number reporting CO concentrations above the level of the CO standard declined to zero over the same period [10].

The second important finding to draw from this study is the possibility that such monitoring may simulate the exposure that would be experienced by a tourist traveler and be used to advise him or her as to the advisability of travel to the locale. Exacerbation of pre-existing cardiovascular disease with an associated increase in cardiac deaths from ischemic heart disease, congestive heart failure and cardiac rhythm disturbances are the main concern for low-level CO exposure. Studied effects of CO on individuals with cardiac disease have demonstrated that increasing blood carboxyhemoglobin (COHb) by 2% has deleterious effects with regard to exercise-induced angina and dysrhythmias [9]. Because cardiovascular effects have been most clearly demonstrated, the EPA's limit for ambient CO is that level which correlates with a blood COHb level of 2%.

The third important finding of this study is the actual severity of the problem currently existing in Vietnam. Ambient CO levels greater than 15 ppm were commonly measured in Vietnam. Over 90% of such measurements were made while walking beside or traveling within heavy traffic. They are the levels to which commuters in Vietnam are exposed and are in agreement with the prior findings of Saksena, et al. [5]. Vietnam is obviously not subject to the standards of the U.S. Clean Air Act. However, the World Health Organization (WHO) guidelines for CO [11] (less stringent than the US Clean Air Act) are:

- 90 ppm for 15-minute mean
- 50 ppm for 30-minute mean
- 25 ppm for one-hour mean
- 10 ppm for eight-hour mean

Because CO levels over 50 ppm were measured several times in traffic in Vietnamese cities of various sizes, it is certainly likely that commuters are routinely and regularly exposed to CO levels exceeding WHO guidelines. In 2010, WHO released air quality guidelines for indoor air quality [13]. Based upon a review of new epidemiologic studies using very large

databases and thus producing very high resolution findings, it was concluded that a maximum CO level of 6 ppm for a 24-hour exposure was appropriate to address the issue of chronic low-level exposure.

In the paper by Saksena et al., the authors wrote,

> "*The survey has clearly provided evidence of the extremely high levels of pollution experienced by commuters, thereby justifying the need for a larger and more comprehensive assessment of human exposures and the factors that influence exposures.*"

The present study supports that assessment.

It has been suggested that Vietnam's cities follow the example of Bangkok, Thailand, and develop subway systems and skytrain systems [14]. It is clear that mass transportation of some type must be developed or the pollution in these cities and this country will only worsen as the population continues to grow. Further, as the economy develops, incomes will rise and commuters will shift to automobile use, with attendant traffic congestion and increase in air pollution as has been seen in Beijing.

Conflict of interest
The authors have declared that no conflict of interest exists with this submission. ■

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