Indoor, Outdoors and In Transit Exposure to Carbon Monoxide in Trujillo, Peru

Manuel F. Aguilar Villalobos

Asociacion del Aire Ambiental, San Borja, Lima, Peru; Municipality of Trujillo; Regional Office of the National Police of Peru; Regional Branch of Peru's Public Health Organization; G.U.E. Sanchez Carrion

ABSTRACT : Carbon monoxide (CO) is a colorless and odorless ubiquitous poisonous gas produced by natural and anthropogenic activities. In developed countries there is a positive association between daily fluctuations in nonaccidental mortality and ambient CO at low concentrations (0.5 - 6.1 PPM). In developing countries CO toxicity may be a more serious problems because it is enhanced by higher CO concentrations, undernourishment of the population, rapid urban growth and land-use changes.

RESUME : Le monoxide de carbone (CO) est un gaz toxique, incolore et inodore, que l'on trouve partout, et qui est produit par des activités naturelles et anthropogéniques. Dans les pays développés, il existe un lien positif entre les fluctuations journalières de la mortalité non accidentelle et la présence ambiante de CO à de faibles concentrations (0,5 – 6,1 ppm). Dans les pays en développement, la toxicité du CO peut devenir un problème plus sérieux parce qu'elle est aggravée par des concentrations de CO plus fortes, ainsi que par la sous-alimentation, la forte croissance urbaine et les modifications qui interviennent dans l'occupation du sol.
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1. *Introduction*

Natural and anthropogenic activities produce complex varieties and quantities of air pollutants that affect public health, agriculture, weather, etc. Estimation of personal exposure to air pollutants is necessary for the evaluation of high-risk populations and to design productive control strategies. However, it is difficult and costly to measure personal exposure. Hence, data of air pollution patterns in microenvironments linked to personal activity data are used as surrogates (Ref. 1).

Human development is the result of a complex inter-relationship between genetic and environmental factors. Genetic factors are important for the how and when human development takes place. Environmental factors can modify human development from before conception until death (Ref.. 2).

Carbon monoxide (CO) is a colorless and odorless ubiquitous poisonous gas produced by natural and anthropogenic activities. In nature, CO is formed as an intermediate product during the photochemical oxidation of methane and non-methane hydrocarbons to carbon dioxide (CO2) and it is also produced by the photooxidation of organic molecules in surface waters and soils.

In the mammalian cellular system, endogenous and exogenous processes produce CO. Endogenous CO production is based on the breakdown of heme pigments. Endogenous C0 production varies considerable for normal individuals and it is affected by several physiological factors that include age, sex, rate and nature of metabolism, tidal volume, body weight, altitude above sea level, permanent and temporarily health conditions, etc (Ref.3,4). The exogenous CO production process is affected by the external supply of carbon monoxide, which upon uptake and metabolism produce detrimental effects in the mammalian cellular system. Upon inhalation of air contaminated with carbon monoxide (CO), this gas rapidly diffuses across alveolar, capillary and placental membranes, binds to hemoglobine and reaches many human organs. The affinity of hemoglobin for CO is 200-250 times that for oxygen (Ref. 4).In the brain CO uptake into tissues begins with the first pass of blood-borne CO through the brain (Ref. 5). Carbon monoxide can definitively affect muscle oxygenation, with effects that are superimposed on those from hypoxia. CO binding to blood shifts the oxyhemoglobin dissociation curve to the left so that delivery of oxygen to muscle cells as well as to all other cells in tissues is impaired (Ref. 6,7).

At low exposure levels, approximately 80-90% of the absorbed CO binds with hemoglobin to form carboxyhemoglobin (COHb), a traditional biomarker of CO exposure in blood. At higher concentrations, CO binds with other heme proteins such as myoglobin, with cytochrome oxidase and cytochrome P-450 (Ref. 8,9)

The toxic effects of CO first become evident in organs and tissues with high oxygen consumption, such as the brain, heart, exercising skeletal muscle and the developing fetus (Ref. 8). It is recognized that carbon monoxide susceptible population groups include not only patients with cardiovascular, pulmonary and respiratory disease but also normal subjects, particularly the pregnant woman, the fetus in the utero, the newborn infant and the elderly (Ref. 9). Changes in metabolism with age make the aging population particularly susceptible to the effects of CO. Maximal oxygen uptake declines with age. Thus it is possible that low levels of CO exposure might be enough to critically impair oxygen delivery to the tissues in this aging population and limit daily metabolic requirements (Ref. 9)

Carbon monoxide may be the cause of more than one-half of the fatal poisonings reported in many countries (Ref.10). In developed countries, there is positive association between daily fluctuations in nonaccidental mortality and ambient levels of CO at concentrations that meet the World Health Organization guide lines and the USA EPA standard for air quality. (Ref.11 to 18). In developing countries, carbon monoxide toxicity could be a more serious problem than in developed countries. In developing countries it is theorized that CO poisoning is enhanced by higher CO concentrations, lack of or failure to enforce environmental regulations, undernourishment of the population, limited know-how and lack of financial resources for environmental research, rapid urban growth and land-use changes (Ref. 19 to 30).

There are studies that have found a positive association between CO exposure and low birth weight. In a study of 125,000 births in Los Angeles, California, USA, 2.2% of these children were born with low weight (Ref. 31). A recent publication in Los Angeles, California, also relates CO exposure to birth defects (Ref.. 32). A study in Guatemala, a developing country, reports that 16.8% to 19.9% of the children were born with low birth weight (Ref. 33).

Carboxyhemoglobin (COHb) is a steady-state condition biomarker for exposure to CO and its production takes several hours to stabilize. However, in transit exposure conditions, CO uptake is a fast process and, since its inhalation, in few seconds it reaches the brain, heart, etc. In vitro studies had shown that exposure to CO at 10-100 PPM for at least 1 hour produces cell necrosis and these studies have theorized that COHb is not a good biomarker at atmospheric CO concentrations that are found in many urban cities. The transient CO exposure condition concept is of particular interest for the understanding of carbon monoxide poisoning of high-risk sub-populations such as a pregnant woman and her fetus. The CO uptake and elimination of the mother and the fetus differ from one another and COHb of the fetus could be significantly higher than that of a normal person (Ref. 3, 34, 35, 36).

The effects of CO have not been thoroughly investigated in populations living at altitudes. At altitude there is an increased body burden of COHb and will attain the COHb level associated with Air Quality guidelines or standards more quickly when breathing CO. (Ref. 37 to 39).

Anthropogenic activities that produce CO include motor vehicle emissions, combustion of biomass and fossil fuels and cigarette smoke. CO is a primary pollutant and is covered by legislation in many countries. The World Health Organization CO Air Quality guidelines for Western Europe and at sea level are based on an endogenous carboxyhemoglobine (COHb) of no more than 2.5%. The USA EPA CO standard is based on an endogenous COHb of no more than 2.0%.(Ref 8, 9).

Motor vehicle emissions are a major source of urban CO. Depending on the driving conditions and engine performance, a motor vehicle with no emission control system is capable of emitting 6,800 to 23,000 PPM of CO every second the engine is operating. In developed countries, the implementation and enforcement of environmental legislation have reduced in more than 95% CO vehicle emissions. In many developing countries there is not legislation to reduce vehicle emissions. In addition to this, the rapid unplanned growth rate of population and urban development has created many street canyons where it is difficult to diffuse the high CO vehicle emissions and there is a real potential for acute short-term exposure to CO (Ref. 40 to 43). In many cities in Peru, it is a common daily experience to see people walking in between congested motor vehicle traffic and thus being exposed to extremely high instantaneous CO concentrations.

We are not aware of any other study on environmental exposure done in Peru. In this study, during June 2001, we report integrated and continuos measurements of exposure to CO in representatives indoors, outdoors and in transit microenvironments in Trujillo, Peru, at sea level and inside a motor vehicle from sea level to 2,500 meters above sea levels.

related to mal nutrition and anemia; of 10 children, 6 are poor and 3 can not cover their basic needs.

Method

Measurements of personal exposures constitute an accurate and reliable method for the exposure to environmental pollutants. However, it is expensive and it takes a long time to measure personal exposures of a significant number of people in a

Table No. 1: Demographic data for Trujillo, Peru

Year	Area (Km2)	People	Vehicles	Peo/Km2	Peo/Veh	Veh/Km2
1972	1,768	394,273	No data	223	No data	No data
1994	1.768	620,162	32.556	350	19.05	18.40
1995	1,768	639,209	37,849	361	16.89	21.40
1996	1,768	658,841	44,023	373	14.97	24.90
1997	1,768	676,924	45,860	383	14.76	25.90
1998	1,768	695,279	49,555	393	14.03	28.02
1999	1,768	713,952	52,898	404	13.50	29.90
2000	1,768	732,592	53,614	414	13.66	30.30

Note: peo/km2 = people per square kilometer; peo/veh = people per vehicle; veh/km2 = vehicles per square kilometer.

Peru is characterized as a country where many people live in high altitudes above sea level. Many important cities and the main tourist destinations are located at more than 2,500 meters above sea level. In 2,001, Peru adopted as its own CO standard the World Health Organization Air Quality guidelines applicable to Western Europe and at sea level. Air quality monitoring is in charge of the Health Ministry. Lima, Peru's capital, is the only known city to have an organized air quality monitoring system. Trujillo does not any air quality monitoring facilities.

In Peru on 1,970, on the average people disposed of S/. 7.00 soles ($2.05) for the purchase of a basic food basket. In 2,001 people disposed of S/ 2.70 soles ($ 0.79) for the purchase of the same basic food basket. In 2,001 it was estimated that 50% of Peruvians lived in poverty and that children are severely affected by this situation. It was estimated that in children, the most serious health problems are

city. Hence, an acceptable alternative is to measure pollutant concentrations in a number of microenvironments and determine the time spent by individuals in these microenvironments (Ref.44, 45).

The local City's mayor helped organized a multi-institutional team to identify representative microenvironments where people expend their daily time and to carry on the design of this study. Local people were trained on how to operate the CO monitor, identify all direct CO sources, keep count and type of motor vehicles at the microenvironments during CO readings and 2 policemen provided needed security.

Basic Data on Trujillo

Trujillo is located at sea level in the western region of South America and in the northern part of Peru. In 2,000, it housed 732,600 people and had a registered motor vehicle fleet of 53,614 units. In the last 30 years, the population in Trujillo has almost doubled and this condition led to an unplanned urban growth rate and rapid change in land-use to house and provide needed services for this people. Table 1 includes basic demographic data for Trujillo.

The study was designed to measure CO exposure concentrations from 6.00 A.M. to 8.00 PM in 15 different microenvironments. Care was taken to identify direct CO sources. In mass transit vehicles measurements were taken at 3 different locations. In indoor microenvironments measurements were taken at curbside, just before entering and inside the premise. In outdoors microenvironments measurements were taken every 50 meters and on both side of the sidewalks.

The Langan T15d high-resolution personal exposure monitor measured CO concentrations. This monitor consists of a passive flow electrochemical sensor, a temperature sensor and a data logger that recorded CO measurements every minute. However, this monitor has the capability to display instantaneous CO readings every second. The Langan CO monitor was calibrated and operated according to the manufacturer's recommendations. Due to technical difficulties to download CO data from the Langan monitor, manual readings were taking every 2 minutes.

The Bacharach Monoxor II High Range CO gas analyzer measured CO motor vehicle emissions at idle and at the tail pipe. This analyzer was operated in accordance to the manufacturer's recommendations.

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Table No. 2: Daily CO arithmetic exposure averages (X in PPM), in Trujillo, Peru

Microenvironment	**No. Sampled**	**X/Microenviron**	**Minimum**	**Maximum**
Indoors	3 buildings	(1.1, 1.2, 2.8)	0.17	17.55
Outdoors	4 streets	(3.2; 3.8; 4.4; 5.9)	0.10	22.30
In Transit	5 types	No daily average	0.21	32.66
Huaca "La Luna"	1	0.69	0.48	0.92
Chan Chan	1	0.70	0.50	0.91

Note: X/Microenviron = daily arithmetic average per microenvironment. Huaca "La Luna" and Chan Chan are historic structures that belong to ancient residents of Trujillo.

Table No. 3: 2 minutes maximum and minimum CO measurements (PPM) in studied microenvironments in Trujillo and known similar other studies used as reference.

Microenvironment	CO Readings (PPM)	Other studies (as reference)
Open Market	0.50 - 24.72	Mexico: 2.00 -70.00
Municipality Building	0.59 - 17.55	Boston: 0.00 - 0.50
Newspaper Building	0.42 - 3.60	Boston: 0.00 – 0.50
Girls High School	0.17 – 4.72	Boston: 0.00 – 0.50
Ayacucho Street	0.35 – 20.50	Guatemala: 0.00 – 10.00
Orbegoso Street	0.25 – 10.98	Guatemala: 0.00 – 10.00
Pizarro Street	0.02 – 22.30	Guatemala: 0.00 – 10.00
Gamarra Street	0.77 – 18.37	Guatemala: 0.00 – 10.00
Taxi (gasoline)	2.49 – 30.30	Los Angeles: 0.50 – 20.00
Taxi (diesel)	2.62 – 25.19	Hong Kong: 2.00 – 4.00
Motorcycle (2 strokes)	0.96 – 21.54	Europe: 0.97 – 4.59
Small Bus (diesel)	0.21 – 9.92	Hong Kong: 1.50 – 4.70
SUV*	1.13 – 32.66	No reference
Huaca "La Luna"	0.49 – 0.90	No reference
Chan Chan	0.55 – 0.91	No reference

***Note:** SUV CO readings taken during a trip from Trujillo, at sea level, to Otuzco at 2,500 meters above sea level.

The main direct source of CO is motor vehicle emissions. Peru does not have a local automotive industry and depends on the importation of this product. Local motor vehicles are not equipped with emissions control systems and, vehicle ownership and driving habits, are conducive to enhance CO emissions. The recorded CO data demonstrates that, in outdoors and in-transit microenvironments, CO concentrations were proportional to motor vehicle density in the nearby surroundings, although this relationship was not always linear. In heavy density motor vehicle areas, the recorded CO concentrations exhibited a not linear proportionality to motor vehicle congestion in the nearby surroundings. In the downtown area that includes several sections of Pizarro, Gamarra, Ayacucho and Orbegoso streets, the design of buildings and of the motor way, created street canyons where emissions from congested motor vehicles resulted in very high instantaneous CO readings. In indoor microenvironments, the proximity of the studied premise in relation to a motor way and its motor vehicle traffic density significantly affected the recorded CO concentration. The presence of natural and artificial ventilation also affected the recorded CO concentrations.

In Trujillo, 230 vehicles were tested at idle to measure CO emissions at the tail pipe during 1-minute engine operation. The CO arithmetic emission averages were 26,300 PPM for motorcycles, 21,930 PPM for gasoline vehicles and 816 PPM for diesel vehicles. For gasoline powered vehicles, the gross emitters represent 20.80% of the tested units (29 vehicles) and this data is positively associated with gross emitters of the most CO polluter vehicles that have been studied in the World (Ref. 46). Analysis of gross vehicle emitters shows that vehicle age is not a guarantee for low CO emissions. Base on motor vehicle model year for gross emitters; 16% are of 1,996; 12% are of 1,995 and 1,988; and, 8% are of 1,994, 1,993 and 1,992; the remaining balance include vehicles from 1,999 to 1,969 model years. Maximum CO emission (91,150 PPM) was measured in a 1,996 model year car. Minimum CO emission (300 PPM) was measured in a 1,984 model year car.

Biomass and fossil fuels combustion mainly used for cooking are important direct CO sources. On visual observation, the different cooking devises used lack maintenance, are located in small enclosed areas with limited ventilation and, in most public premises, large number of people seat and eat in close proximity to these C0 sources. The most popular observed biomass and fossil fuels used were: wood fuel; coal briquette, charcoal and kerosene. There are no known environmental regulations for the use of these fuels. Inside public premises, it was common to find overhead funs, which are used only during the summer season to alleviate high temperatures. People do not understand the importance of the rate of air exchange in indoor microenvironments as a mean to reduce CO concentration (Ref. 47 to 49).

Cigarette smoking is another important direct CO source. Although Peruvian legislation prohibits smoking in public places, many people smoked in all of the studied microenvironments. There are not known smoking habits studies in Trujillo nor in Peru.

Recommendations

1. - Recording of CO measurements should be done at shorter time intervals than the 2 minutes used in this study. Humans inhale air every 10 -12 seconds and CO uptake takes few seconds. Very high instantaneous CO readings were noticed but could not be registered because of the 2 minutes recording criteria.

2. - Peru and Trujillo should design and deploy an educational program to teach people on the detrimental effects of air pollution and on how to protect themselves from its ill effects. In 1,998 it was reported that in Lima, air pollution killed 8 people per day. People should use the installed overhead fans as a means to increase air rate exchange in indoors microenvironments and not only to alleviate high temperatures during the summer season.

3. - Peru and Trujillo need an environmental policy to protect public health that is based on local needs. The WHO guidelines for Air Quality are applicable to Western Europe and at sea level. Peru is characterized by having people living at high altitudes above sea level and the sanitation; nutrition; health; social and economic conditions are much different than those in Western Europe.

4. - Peru and Trujillo need to promote the use of the most environmentally advanced motor vehicles. It has been proven that the most productive method to reduce environmental CO concentrations is to use motor vehicles that minimized CO emissions. Depending on the source, environmentally advanced vehicles may not necessarily cost more than present imported vehicles.
It is not acceptable that the present motor vehicle fleet of 1.3 million units are damaging the health of 25 million Peruvians and that they are inflicting severe damages to the environment where it is going to be difficult to live for future Peruvian generations.

5. - It will help to obtain the cooperation of the international community to promote the research of needed environmental issues in Peru.

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