Yonsei Medical Journal
Vol. 35, No. 4, 1994

Determinations of Personal Carbon Monoxide Exposure and Blood Carboxyhemoglobin Levels in Korea

Yong Chung, Seong Eun Park, Kiyoung Lee[1],
Yukio Yanagisawa[1] and John D. Spengler[1]

Determinant factors for personal carbon monoxide (CO) exposures were sought in Korea, where CO poisoning has been a major public health problem due to coal briquette (Yeontan) combustion for space heating and cooking. Personal 24-hr CO exposures of 15 housewives were measured by CO passive samplers on 2 days of the week (Wednesday and Sunday). Blood samples were taken to measure carboxyhemoglobin (COHb) just after the exposure sampling. Average CO exposure and COHb level were 5.6 ppm and 2.4%, respectively. Personal CO exposures as well as COHb levels were significantly increased by the use of Yeontan, especially on a weekday. Carboxyhemoglobin levels were closely related to the time between blood collection and replacement of Yeontan: the closer the blood collection was to replace Yeontan, the higher the COHb levels were. Assuming a background COHb of 1.34%, COHb increased on average by 1.8% with a 24-hr personal CO exposure of 10 ppm. The relationship between CO exposure and COHb level was provided by simultaneous direct measurements in real environment, although a measurement of COHb at the end of exposure could not represent previous 24-hr exposure thoroughly.

Key Words: Carbon monoxide, carboxyhemoglobin, coal briquette(Yeontan), personal exposure

Carbon monoxide (CO) poisoning in Korea has been a major health problem due to the usage of coal briquette, called Yeontan, for space heating (Chung *et al.* 1990). In addition to several thousand deaths, over one million people suffered from CO poisoning during the year of 1965~1976 (Kim 1985). Carbon monoxide can be released into a house by inadequate maintenance or improper installation of the coal briquette (Ondol), the traditional Korean heating system using Yeontan. The hot exhaust gas from the coal briquette combustion is passed through a gas tight space under the floor of a room to warm the floor and is then discharged to the outdoors through a chimney, usually placed at opposite side of house from the coal briquette combustion site. There is a renovated heating system, called an Yeontan Boiler, which uses hot water as the medium for the floor heating. Although many of the heating systems using coal briquette have been modified to use other type of fuel, e.g. oil or gas, the risk of CO poi-

Received July 4, 1994
Accepted November 3, 1994
Department of Preventive Medicine and Public Health, Yonsei University College of Medicine, Seoul, Korea
[1]Harvard School of Public Health Dept. of Environmental Health 665 Huntington Ave. Boston MA, 02115
This study was oral presented at the 4th annual meeting "International Society for Environmental Epidemiology and Exposure Analysis", Cuernavaca, Morelos, Mexico, 1992
Address reprint request to Dr. Y Chung, Department of Preventive Medicine and Public Health, Yonsei University College of Medicine, C.P.O. Box, Seoul 120-752, Korea

soning remains a major threat to public health in Korea. Approximately 67.8% of all house in Korea (about 4 million houses) still use the coal briquette heating system (Chung *et al.* 1990).

Significance of CO poisonings in Korea can be determined by the comparison with CO poisonings in the United States. Average unintentional death rate from CO poisoning in the US population was 0.51 per 100,000 people per year in the period, 1979 through 1988 (Cobb and Etzel 1991). Total unintentional CO poisoning deaths were 11,547 in the US population for this 10-year period. Although death rate from unintentional CO poisoning in the Korean population is not available, the incidence of CO poisoning in Seoul, Korea, has been investigated in 1984 (Cho *et al.* 1985). Age-adjusted CO poisoning incidence rate was 4,070 per 100,000 people. Among the CO poisoning cases investigated, about 0.3% of the incidences resulted in death. Therefore, the death rate from CO poisoning can be estimated to be about 12.2 per 100,000 Koreans. This death rate may include intentional and unintentional deaths. Since the death rate of CO poisoning in the US including intentional and unintentional deaths is about 1.5 per 100,000, the death rate from CO poisoning is about eight times higher in Korea than in the United States.

When the traditional coal briquette heating system is properly installed and maintained, CO exposures are not usually at harmful levels. However, studies have investigated the harmful effects of the traditional heating system due to personal CO exposure (Kim 1985). In addition to fatal CO poisoning, low or moderate CO exposures from the heating system should not be ignored. Nonspecific symptoms like headache, nausea, vomiting, dizziness, and coma have been reported in these low to moderate CO exposures. Healthy individuals exposed to low levels of CO can exhibit decreased alertness, while the symptoms of heart disease patients can be aggravated by exposure to low levels of CO (Adams *et al.* 1988). Therefore, determining the effects of the heating system by measuring personal CO exposures is necessary in order to determine exposure characteristics in the general population of Korea.

Carbon monoxide interferes with oxygen transport in the human body by producing carboxyhemoglobin (COHb). Carbon monoxide is one of the few air pollutants of which its absorption by the body can be determined. The amount of CO absorbed from CO exposure can be determined by the percentage of blood COHb or/and CO in exhaled air, since most CO in the body is bound to Hb and CO is eliminated only via the lung. Measurement of exhaled CO have been used to determine CO exposure (Verhoeff *et al.* 1983; Wallace and Ziegenfus 1985). The effects of CO exposure on blood COHb or exhaled CO were usually determined on constant CO exposures, unlike fluctuating environmental concentrations (Peterson and Stewart 1970; Coburn *et al.* 1965).

The US National Ambient Air Quality Standard (NAAQS) for CO, which is based on measurement made at fixed site monitor, is set to prevent occurrence of COHb level above 2% (Federal Reg 1985). Carboxyhemoglobin level is used to determine health effects of CO exposure. The relationship between exposure and COHb level is important since the compliance of the standard is based on exposure for a certain COHb level. However, few studies have been conducted to determine the relationship between CO exposures and COHb levels in environmental settings. Carboxyhemoglobin levels were not closely related with the exposures estimated by ambient CO levels from fixed monitors (Wallace and Ziegenfus 1985). The insignificant relationship can be explained by the inability of a fixed monitoring station to estimate personal CO exposure (Cortese and Spengler 1976). Accurate characterization of personal exposure is needed for valid assessment of health effects and the design of more effective interaction strategies(Samet and Spengler 1991).

This study was conducted to determine the effect of the traditional heating system on CO exposure in Korea as well as to establish the realtionship between personal CO exposure and COHb level under environmental conditions.

MATERIALS AND METHODS

Fifteen housewives were selected from Dongdaemoon-Ku in Seoul, Korea, which has a large number of Yeontan users. Yeontan was used by 71.9% of population for heating and 12.4% of the population for cooking in this district (The Korean Statistical Association, 1990).

The 15 volunteers were divided into three groups: 5 housewives below age 40 using Yeontan (boiler), 5 housewives above age 40 using Yeontan (boiler) and 5 housewives from 35 to 46 years old who do not use Yeontan.

Personal CO exposure was measured by a CO passive sampler which is a tube-type sampler using ion exchanged zeolite as solid adsorbent (Lee *et al.* 1992). The subjects wore the CO passive sampler for two 24-hr days, Wednesday and Saturday in March, 1992, placing it in the bedroom while sleeping. Each exposure sampling day began in the morning and finished at the same hour the next morning. The exposed samplers were analyzed by gas chromatography with a flame ionization detector (Shimadzu Co. model GC-8A, Japan) at the Harvard School of Public Health.

The blood from each subject was an aerobically collected in the morning, just after the exposure sampling. Blood samples were stored in an EDTA tubes inside an ice box at 4℃. Total hemoglobin, oxyhemoglobin (O_2Hb), COHb, and methylhemoglobin (MetHb) were analyzed within 3 hours of blood collection by a CO-oximeter (Instrumentation Laboratories, IL 482) from Yonsei University. The instrument can measure the proportion of O_2Hb, COHb, and MetHb using absorbance and molar extinction coefficients at several wavelengths in the visible region. After the completion of the CO exposure and COHb analysis, the results by the two institutes were exchanged in order to meet double-blined procedures. Information about heating system, housing characteristics, smoking, and health status was collected by questionnaire from subjects before the sampling. The daily activities of subject in one-hour intervals were recorded by the subject during the sampling in a daily activity log sheet containing location and time spent.

RESULTS

Personal CO exposures for 24 hours ranged between 0.6 and 11.5 ppm with the average of 5.6 ppm, as shown in Table 1. Three CO exposure values were missed due to analysis errors. Four duplicate CO passive samplers were used to determine the precision of CO measurements. The average difference for the duplicates was 2.1 ppm. Carboxyhemoglobin levels ranged from 1.2% to 5% with the average of 2.4%. The average total hemoglobin amount was 13.1g/dL with an average O_2Hb of 64.7%. The MetHb average was 0.4%. The distributions of personal CO exposures and COHb levels were shown in Figure 1.

The personal CO exposures and COHb le-

Table 1. Descriptive statistics of measurement variables

	CO(ppm)	COHb(%)	Total Hb(g/dL)	O_2Hb(%)	Met Hb(%)
Average	5.6(5.4)*	2.4(2.2)*	13.1	64.7	0.4
S.D.	2.5	0.8	1.6	13.1	0.2
Min.	0.6	1.2	9.1	43.1	0.1
Max.	11.5	5.0	16.5	90.6	1.0
No.	27*	30	30	30	30

*Values excluding one subject who has high COHb
**Three cases are excluded because of missing values.

Table 2. CO exposure and COHb levels classified by several factors

Variable		No.	COHb(%)		CO(ppm)	
			Mean	S.D.	Mean	S.D.
Briquette	Yes	20	2.63*	0.91	6.10	2.55
	No	10	1.93	0.40	4.82	2.33
Smoking[1] (cigarette)	<10	18	2.37	0.98	5.42	2.94
	≥10	12	2.44	0.59	5.98	1.63
Week	day	15	2.19**	0.87	4.59*	2.33
	end	15	2.61	0.76	6.93	2.18
Age (years)	<40	14	2.11**	0.65	5.03	2.78
	≥40	16	2.65	0.98	6.10	2.23
Distance to road	Next	14	2.20	0.72	5.04	1.58
	Close or far away	16	2.56	0.91	6.10	3.03
CO poisoning experience	Yes	12	2.56	0.91	5.65	2.15
	No	18	2.16	0.66	5.59	2.97

[1]Smoking of 10 cigarettes inside house
*p<0.05 **p<0.01

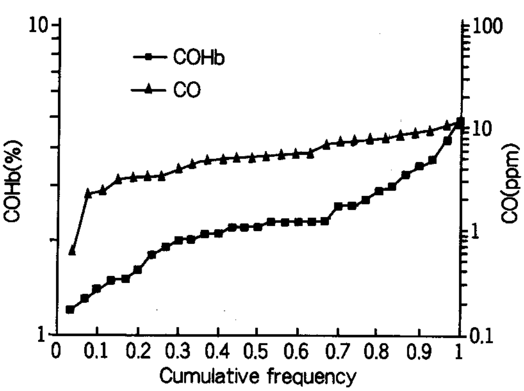

Fig. 1. *Distribution of CO exposures anf COHb levels in the subjects.*

vels were divided to two groups on the basis of the use of Yeontan, age of 40, day of the week the measurement was made, CO poisoning experience, distance to road, and smoking of 10 cigarettes inside house, as shown in Table 2. When the effects of the variables were determined by the Wilcoxon Rank Sum Test, personal CO exposures were not significantly affected by the use of Yeontan, but COHb increased significantly ($p<0.05$). Carboxyhemoglobin levels of subjects above age 40 were significantly higher than in subjects below age 40 ($p<0.01$), although personal CO exposure were not affected by the age. When the subjects were also divided into two groups by CO poisoning experience and distance from the road, CO exposure and COHb were not significantly affected by either factor. Although all subjects were not smokers, all houses had more than one smoker. Therefore, subjects were divided by smoking of 10 cigarettes inside house. Carbon monoxide exposure and COHb were not significantly affected by the smoking of cigarette.

Significant independent variables for CO and COHb were selected by stepwise multiple analysis. The use of Yeontan was selected in both regression models for CO and COHb ($p<0.05$). In addition to the use of Yeontan, the day of the week and the age of 40 were selected as independent variables in regression

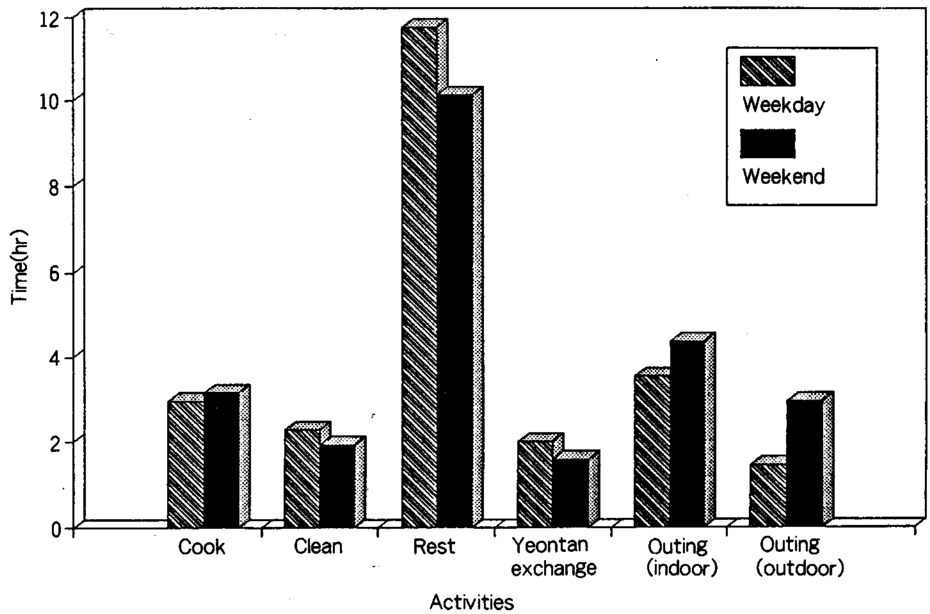

Fig. 2. *Time for each activity in weekend and weekday.*

Table 3. Effects of Yeontan in weekday and weekend **mean±S.D**

	Use of Yeontan	COHb(%)	CO(ppm)
Weekday	Yes	2.44±0.94	5.35±2.26
	No	1.68±0.38	3.06±1.59
Weekend	Yes	2.82±0.84	7.18±2.54
	No	2.18±0.22	6.58±1.46

models for CO and COHb, respectively. However, smoking, distance from the road and CO poisoning experience were not selected as independent variables at the significance level of 0.1.

When CO exposures and COHb (weekend to weekday) were compared by Wilcoxon matched-pairs signed ranks test, CO exposures ($p<0.05$) and COHb levels ($p<0.01$) on the weekend day were significantly higher than on the weekday. Increases of CO exposure and COHb by the use of Yeontan were higher on the weekend day than on weekday, as shown in Table 3. The significance levels for the effects of use of Yeontan in weekday were 0.15 and 0.08 for COHb and CO exposure, respectively (Wilcoxon signed rank test). Carbon monoxide exposures and COHb on the weekend day were not affected by the use of Yeontan. However, the 24-hr CO exposures and COHb levles of all subjects on weekend day were higher than 5 ppm and 2%, respectively, regardless of the use of Yeontan.

Most subjects stayed at home longer on the weekday than on the weekend day, as shown in Figure 2. Average times outside the home were about 4.8 hours on the weekday and 7.2 hours on the weekend day. The average time was calculated from the daily activity log sheet using one-hour intervals. Although the subjects stayed home longer on the weekday, the proportion of each activity in the home, such as cooking, cleaning, rest (including sleeping), and changing Yeontan, did not change, (less than 3% between weekday and weekend day). The proportion of each activity time was not different between the Yeontan user and non-user.

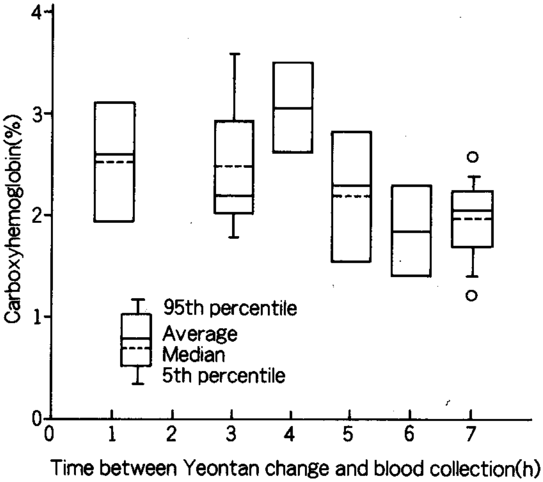

Fig. 3. *Effects of the time between Yeontan changes and blood collection on carboxyhemoglobin level.*

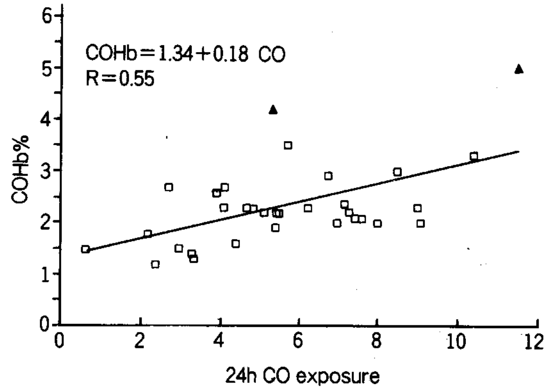

Fig. 4. *Relationship between COHb and 24h CO exposures.*
(Asterisk is person who had more than three CO poisoning experiences.)*

Self-reported CO poisoning experiences were divided by the use of Yeontan, age, and smoking of 10 cigarettes inside houses. Carbon monoxide poisoning experience did change with the use of Yeontan and age. Forty percents of the subjects (2/5) not usually using Yeontan reported more than one CO poisoning experience. The proportion of CO poisoning experience increased to 70% for subjects using Yeontan (7/10). Carbon monoxide poisoning experience increased from 43 percent (3/7) in subjects below age 40 to 75 percent (6/8) above age 40. However, CO poisoning experiences were not affected by the number of cigarettes smoked inside house.

Carboxyhemoglobin levels were inversely related to the elapse time between the replacement of Yeontan and the blood sampling, as shown in Figure 3, unlike CO personal exposures ($p=0.514$). When the time between Yeontan replacement and blood collection was less than 5 hours, COHb levels were 2.51 ± 0.67 %. However, COHb levels were $1.96\pm0.40\%$ when the time was longer than 5 hours or when the subjects did not use Yeontan at all. The COHb levels divided by the elapse time of 5 hour were significantly different (Wilcoxon rank sum test, $p<0.01$). Carbon monoxide exposure and COHb were not affected by the time between cooking and blood collection.

The relationship between COHb and 24-hr CO exposures was determined by linear regression. The intercept and slope of the linear regression model were 1.34 and 0.18, respectively, R^2 of 0.5551, as shown in Figure 4. The multiple regression with two independent variables, such as CO exposure and weekday, was conducted to determine the effects of the day of the week on each subject. The relationship between COHb level and CO exopsure was not affected by the day of week.

DISCUSSION

Participants in the study were housewives who did not work outside the home. Since most females in Korea do not have a job outside the home, in this respect the volunteers were representative of the housewife population in Korea. In fact, the female CO poisoning incidence rate is 1.2~1.6 times higher than it is for males in Korea (Cho *et al.* 1985). Since most housewives manage the heating and cooking and they spend more time at home, the heating system may be a critical factor for CO exposure of housewives. Coal briquette is used in about 4 million houses in Korea. The investigation of the effect of coal briquette on CO exposure can significantly impact public health in Korea.

Carboxyhemoglobin level may be affected not only by CO exposure but also by other factors such as hemolytic anemia and pulmonary disease. One subject who recalled three CO poisoning experiences (twice she was admitted to the hospital for acute CO poisoning) had the highest COHb on both days. When COHb levels and CO exposures of the subject were excluded from the regression between COHb level and CO exposure, the slope and intercept of the relationship between COHb level and CO exposure are 0.12 (s.e.= 0.04) and 1.55 (s.e.=0.50), respectively.

Carboxyhemoglobin levels in 15 volunteers ranged from 1.2% to 5% which is higher than COHb in the US nonsmoker population. When the two highest COHb levels of the one subject were excluded, the average COHb level was 2.24%, while the highest average COHb among 20 cities, found in Washington, D.C., was 1.6% (Wallace and Ziegenfus 1985). About 70% of self-declared nonsmokers in the 20 US cities have COHb levels lower than 1%, although no subjects in this study had a COHb level lower than 1%. When COHb levels in the 65 US geographic areas were analyzed during the period 1976-1980, about 75 percent of nonsmoking US population had COHb level lower than 1% (Radford and Drizd 1982).

The high COHb levels may be due to high CO exposures in Korea. Akland *et al.* (1982) investigated CO exposures in Washington, D.C. and Denver, using personal exposure monitors with datalogger. The exposures in Denver were higher than the exposures in Washington, D.C. Averages of maximum 1 and 8-hr exposures in Denver were 10.2 and 4.9 ppm. Average 24-hr CO exposures may be lower than the maximum 8 hour exposure. Average 24-hr CO exposures in this study was 5.6 ppm which was even higher than the maximum 8-hr exposures in Denver.

In our study, the CO exposures were measured in March when the temperature is not the lowest, so heating system will not be used as much as in the winter months. The exposures to CO may increase in the winter months. Carbon monoxide poisoning admissions in one hospital in Korea peaked in the period from November through February (Kim 1985). In a previous study, personal CO exposures of 22 housewives were measured to be 17.7 ppm in Seoul, January 1989 (Son *et al.* 1990).

The effects of Yeontan on CO exposure and COHb level were significant only on the weekday. The significant effect on the weekday can be explained by the activities which kept subjects at home longer on the weekday. On the weekend day, although the effects of Yeontan on CO exposure and COHb level were not significant, CO exposures and COHb levels were higher than on the weekday (Table 3). This suggests that the volunteers spent more time on weekend days in busy areas for shopping, recreation, and so on, where CO concentrations are higher or that the volunteers spent more time with their smoking husbands on the weekend day. Further investigation is necessary to determine whether CO exposures outside the home are significant.

Carboxyhemoglobin levels significantly increased above the age of 40 with insignificant differences of CO exposures. The multiregression model selected age as independent variable only for COHb level, not CO exposure. Pace *et al.* (1948) reported a decrease of elimination rate of 1% per year over the age of 40; the air exchange rate in the alveolar region may be reduced by the respirocirculatory changes. Although COHb levels significantly increased above age of 40 without a corresponding increase in CO exposure, it is difficult to conclude that COHb levels may significantly increased above the age of 40 from the small number of subjects in this study.

Smoking is a potential indoor source of many pollutants (Dockery and Spengler 1981). All 15 homes in the study had more than one smoker who smoked inside the house. The effects of smoking on indoor concentration may be affected by several factors, such as number of cigarettes smoked, smoking habits, air exchange rate, outdoor concentration, and house characteristics. When CO exposures and COHb levels were classified by number of cigarettes smoked, no difference was found. However, in this study there were no houses without a smoker. Future studies of indoor air pollution should compare between houses with and without smokers.

Carboxyhemoglobin was significantly related with the time between replacement of Yeontan and blood collection. The exhaust gas of a coal briquette contains an average of 3% to 5% of CO (Chung *et al.* 1990). It is likely that housewives are exposed to high CO levels during briquette replacement. Since Yeontan burns for 7 to 8 hours, it has to be replaced to keep fire. A coal briquette combustion site holds two coal briquettes vertically. The bottom briquette burns first and sets fire to the upper briquette. After the bottom briquette has burned out, it is discarded. The burning upper briquette is then placed at the bottom and a new briquette is set over it. Therefore, the housewives are likely exposed to high level of CO during the replacement of Yeontan.

Carbon monoxide absorbed is associated with hemoglobin forming COHb level. Carboxyhemoglobin level is a function of CO inhaled and exposure time. Since total COHb can be divided into endogenous and exogenous COHb, the relationship between COHb level and CO exposure can be expressed by a first order equation (Ott and Mage 1978). The slope of the equation represents the effect of exogenous CO exposure and intercept implies endogenous COHb levels. From the published data, the California State Department of Public Health derived a slope of 0.16 for these equation for a CO concentration under 100 ppm (Goldsmith and Landaw 1968). Coburn found the slope to be 0.15 for similar concentrations (Coburn *et al.* 1965). These values are comparable to the slope of 0.18 derived in this study.

The intercept of the regression line represents a background COHb level endogenously produced by the breakdown of heme protein. The endogenous COHb level is about 0.4~0.7% (Stewart 1976). Although the intercept in this study was higher than the endogenous level, they were not statistically significantly different. The difference from the published intercept value in this study may be due to small number of subjects.

The correlation coefficient in the regression model between COHb level and 24-h personal CO exposure was 0.55 with the direct measurement of CO exposure. The moderately low coefficient can be explained by several variables such as fluctuating ambient concentration, personal physiological differences, and various activities which change alveolar ventilation rate. The measurement of COHb or alveolar CO is the best estimate of CO in the body at a given time. However, the measurement of COHb or alveolar CO at the end of an exposure may not be enough to estimate the preceding 24 hour exposure throughly.

REFERENCES

Adams KF, Koch G, Chatterjee B, Goldstein GM, O'Neil JJ, Bromberg PA, Sheps DS, McAllister S, Price CJ, Bissette J: Acute elevation of blood carboxyhemoglobin to 6% impairs exercise performance and aggravate symptoms in patients with ischemic heart disease. *J Am Coll Cardiol 12: 900-909, 1988*

Akland GG, Hartwell TD, Johnson TR, Whitmore RW: Measuring human exposure to carbon monoxide in Washington, D.C., and Denver, Colorado, during the winter of 1982-1983. *Environ Science Technology 19: 911-918, 1982*

Cho S, Shin YS, Lee DH: A study on the incidence of carbon monoxide poisoning. *Korean J Preventive Medicine 18(1): 1-11, 1985*

Chung Y, Shin DC, Lim YW: Health and social problems of carbon monoxide poisoning from the usage of anthracite coal in Korea. *Korean J Environ Toxicology 5: 57-66, 1990*

Cobb N, Etzel RA: Unintentional carbon monoxide –Related deaths in the United States, 1979 through 1988. *JAMA 266: 659-663, 1991*

Coburn RF, Forster RE, Kane PB: Considerations of the physiological variables that determine the blood carboxyhemoglobin concentration in man. *J Clinical Investigation 44: 1899-1910,* *1965*

Cortese AD, Spengler JD: Ability of fixed monitorig stations to represent personal carbon monoxide exposure. *J Air Pollution Control Association 26: 1144-1150, 1976*

Dockery DW, Spengler JD: Indoor-outdoor relationships of respirable sulfates and particles. *Atmos Environ 15: 335-343, 1981*

Federal Register: "Review of the national ambient air quality standards for carbon monoxide; final rule" *F.R. (September 13). 50: 37484-37501, 1985*

Goldsmith JR, Landaw SA: Carbon monoxide and human health. *Science 162: 1352, 1968*

Kim YS: Seasonal variation in carbon monoxide poisoning in urban. *Korea J Epidemiology and Community Health 39: 79-81, 1985*

Lee KY, Yanagisawa Y, Hishinuma M, Spengler JD, Billick IH: A passive sampler for measurement of carbon monoxide exposure using a solid adsorbent. *Environ Science Technology 26: 697-702, 1992*

Ott WR, Mage DT: Interpreting urban carbon monoxide concentrations by means of a computerized blood COHb model. *J Air Pollution Control Association 28: 911-916, 1978*

Pace N, Strjman E, Walker E: Influence of age on carbon monoxide denaturation in man. *Federation Proceddings 7: 89, 1948*

Peterson JE, Stewart RD: Absorption and elimination of carbon monoxide by inactive young man. *Arch Environ Health 21: 165-171, 1970*

Radford EP, Drizd TAQ: Blood carbon monoxide levels in persons 3-74 years of age: United States, 1976-1980. *Hyattsville, Md: U.S. Department of Health and Human Services, National Center for Health Statistics; DHHS publication no. (PHS) 82-1250, 1982*

Samet JM, Spengler JD: Indoor air pollution; a health perspective. *The Johns Hopkins University Press, 1991*

Son BS, Nitta H, Maeda K, Kim YS, Yanagisawa Y: Measurements of indoor carbon monoxide concentrations and personal exposures in Korea. *J Japan Soc Air Poll 25: 334-342, 1990*

Stewart RD: The effects of carbon monoxide on humans. *J Occup Med 18: 304-309, 1976*

The Korean Statistical Accosiation: Population and housing census report. *1990*

Verhoeff AP, van der Velde HCM, Boleij JSM, Lebret E, Brunekreef B: Detecting indoor CO exposure by measuring CO in exhaled breath. *Int Arch Occup Environ Health 53: 167-173, 1983*

Wallace LA, Ziegenfus RC: Comparison of carboxyhemoglobin concentrations in adult nonsmokers with ambient carbon monoxide levels. *J Air Pollut Control Assoc 35: 944-949, 1985*