Non-Invasive Carboxyhemoglobin Monitoring: Screening Emergency Medical Services Patients for Carbon Monoxide Exposure

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This research was conducted in the Department of Emergency Medicine at Warren Alpert Medical School at Brown and Rhode Island Hospital in Providence, RI in affiliation with the Providence Fire Department. The study was approved by the hospital's institutional review board and received an exemption from obtaining informed consent.

Keywords: carbon-monoxide toxicity; carboxyhemoglobin; emergency medical services; monitoring; patient

Abbreviations:
CO = carbon monoxide
COHb = carboxyhemoglobin
ECG = electrocardiogram
EMS = emergency medical services
EMT = emergency medical technician
IRB = institutional review board
MAP = mean aterial blood pressure
SpCO = pulse carboxyhemoglobin saturation
SpO2 = pulsometry hemoglobin saturation

Abstract

Introduction: Carbon monoxide (CO) toxicity is a significant health problem. The use of non-invasive pulse CO-oximetry screening in the emergency department has demonstrated that the rapid screening of numerous individuals for CO toxicity is simple and capable of identifying occult cases of CO toxicity.
Objective: The objective of this study was to extend the use of this handheld device to the prehospital arena, assess carboxyhemoglobin (SpCO) levels in emergency medical services (EMS) patients, and correlate these levels with clinical and demographic data.
Methods: This was a retrospective, observational, chart review of adult patients transported to hospital emergency departments by urban fire department EMS ambulances during a six-week period. Each ambulance used a non-invasive pulse CO-oximeter (Rad-57, Masimo Inc.) to record patients' COHb concentrations (SpCO) along with the standard EMS assessment data. Spearman's Rank Correlation tests and Student's *t*-tests were used to analyze the data and calculate relationships between SpCO and other variables (age, gender, respiratory rate, heart rate, mean arterial pressure, and oxygen saturation measured by pulse oximetry).
Results: A total of 36.4% of the patients transported during the study had SpCO documented. Of the 1,017 adults included in this group, 11 (1.1%) had an SpCO >15%. There was no correlation between SpCO and heart rate, ventilatory rate, mean arterial pressure, and oxygen saturation.
Conclusions: Screening for CO toxicity in the EMS setting is possible, and may aid in the early detection and treatment of CO-poisoned patients.

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Introduction

Carbon monoxide (CO) poisoning is a significant health problem in the United States. From 2001–2003, >15,000 patients were treated annually in emergency departments for suspected or confirmed, non-fire related, unintentional, CO exposure. During the same time period, nearly 500 people died from CO toxicity each year, making CO the most common cause of unintentional poisoning in the US.[1] The actual prevalence of CO poisoning in the general population is unknown, and many cases are unrecognized.[2,3] Cold weather, mass-casualty incidents, and disasters are associated with an increased incidence of CO toxicity.[4–7]

Carbon monoxide is a non-irritating, colorless, and odorless gas. It is a product of incomplete combustion. While many poisonings are associated with smoke exposure during a fire, there are other significant sources of car-

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bon monoxide. These include motorized vehicle exhaust fumes and improperly functioning heating systems, which when combined with poor ventilation, can result in CO toxicity. Of 11,547 accidental (non-intentional) CO deaths between 1979 and 1988, motor vehicle exhaust accounted for 57%.[8] Elevated levels of carbon monoxide also are associated with tobacco smoke exposure, with smokers commonly COHb saturation reaching levels of 10%, and at times, >15%.[9] When absorbed through the skin, methylene chloride, found in industrial solvents and paint remover, is metabolized into carbon monoxide and can be another noteworthy source.

Poisoning due to CO exposure can result in a constellation of vague symptoms and signs that have significant overlap with many other illnesses, making the recognition of CO toxicity difficult. The nebulous presentation of CO poisoning may point the healthcare professional toward an incorrect diagnosis, treatment plan, and patient disposition. Inadvertently returning a patient to the site of CO exposure may lead to further toxicity and the possibility of long-term neurological, psychiatric, or cardiovascular complications.[10]

Carbon monoxide poisoning is a preventable cause of morbidity and mortality. The use of non-invasive pulse CO-oximetry screening in the emergency department has demonstrated that rapid screening of numerous individuals for CO toxicity is simple and can result in the identification of occult cases of CO toxicity.[11,12] This technology also has been used to diagnose CO toxicity in smokers and in a remote setting to rapidly diagnose CO toxicity in a British Navy submarine under the polar ice cap.[13,14] These successes have raised the question of whether non-invasive pulse CO-oximetry can be applied in other settings to detect CO exposure.

The use of a handheld, non-invasive, pulse CO-oximeter can be extended into the prehospital or emergency medical services (EMS) arena. Assessing carboxyhemoglobin levels non-invasively in EMS patients may provide an opportunity to identify CO poisoning early, initiate treatment prior to arrival to the hospital, immediately warn others of the presence of CO, and determine the prevalence of occult cases. The objective of this investigation was to assess carboxyhemoglobin (SpCO) levels in EMS patients using a non-invasive device, and correlate these levels with clinical and demographic data.

Methods

Study Design, Setting, and Selection of Participants

This investigation was a retrospective, observational study of all patients (≥18 years of age) transported to hospital emergency departments by urban fire department EMS ambulances during a six-week period (September and October 2007). Two months prior to chart review, portable non-invasive spectral analysis pulse CO-oximeters (Rad-57, Masimo, Inc., Irvine, CA) were placed into all six EMS ambulances that service a small US city. The non-invasive pulse CO-oximeter uses a fingertip probe similar to a pulse oximeter and displays the COHb concentration (SpCO) and oxygen saturation (SpO_2) on a digital screen within 10 seconds. The device uses a multi-wavelength sensor with an array of visible and infrared light-emitting diodes (LEDs) to estimate the COHb concentration in the presence of the other three main hemoglobin species, oxyhemoglobin, deoxyhemoglobin, and methemoglobin. The SpCO measurements were documented on the EMS chart by emergency medical technicians (EMTs) and paramedics, along with chief complaint, initial vital signs, and oxygen saturation as part of the standard EMS assessment. All patients were eligible for inclusion in the study if they had vital signs recorded and documented on the EMS record and if they were ≥18 years of age. The study was approved by the hospital's institutional review board and received an exemption for obtaining informed consent.

Data Collection, Processing, and Measurement

Prior to the initiation of the study, all EMTs and paramedics were trained in the use of the pulse CO-oximeter using a standard curriculum, which covered the technical aspects of device operation, and information about CO toxicity, and factors that may affect COHb levels and SpCO measurement. During the study period, two of the authors reviewed all EMS charts and recorded the SpCO along with other variables into an *a priori* constructed database using standard definitions for the variables sampled. Variables recorded in the database included: date, age, gender, chief complaint, SpCO, SpO_2, heart rate, ventilatory rate, and systolic and diastolic blood pressure. When possible, the hospital emergency department data of EMS patients was reviewed to correlate CO levels. Data, in final format, were screened to identify errors in entry. Entries with erroneous data were eliminated from the database.

Primary Data Analysis

Data were processed using STATA v. 9® (STATA Corp., College Station, TX), a standard software program. Descriptive statistics were calculated for the variables including mean, standard deviation, and minimum and maximum values. Spearman's Rank Correlation tests and Student's *t*-tests were used to process the data and calculate relationships between SpCO and other variables (age, gender, ventilatory rate, heart rate, mean arterial pressure, and oxygen saturation measured by pulse oximetry). Statistical significance was set at $p < 0.05$. Mean arterial pressure (MAP) was calculated mathematically from the systolic and diastolic blood pressure variables using the formula: MAP = diastolic blood pressure + 1/3 (systolic blood pressure – diastolic blood pressure).

Results

During the six-week study period, fire department rescue ambulances transported 3,009 patients. Of these, 1,093 (36.4%) had SpCO documented, 1,017 were ≥18 years of age. Five hundred fourteen (50.5%) of those adults with documented SpCO were male. The mean value for age was 47.6 ±20.1 years, with ages ranging from 18–101 years. The mean value for the SpCO was 3.66% ±3.66, with a range of 1–28%. A total of 241 (23.7%) patients had a SpCO >5%, 56 (5.5%) had a SpCO >10%, and 11 (1.1%) had an SpCO >15%. Of the 241 patients with a SpCO >5%, oxygen was administered to 56 patients during transport. Of the 11 adult patients with SpCO >15%, chief complaints included shortness of breath (n = 3), hypoglycemia (n = 2), abdominal pain, alcohol intoxication, chronic rectal pain, generalized body pain, seizure, and toothache (Table 1). Patients with a SpCO >10% were transported throughout the study

Age	Sex	Chief Complaint	HR	RR	MAP	SpO_2	SpCO	Date Transported
42	f	Shortness of Breath	105	24	176	99	28	10/01/07
49	m	Abdominal pain, vomiting, diarrhea	86	18	136	93	26	10/08/07
50	f	Shortness of breath, fever	95	*	107	99	24	10/02/07
43	m	Hypoglycemia	101	*	125	98	23	09/02/07
27	f	Intoxicated	102	18	62	96	23	09/17/07
38	f	Chronic rectal pain	96	16	105	96	21	10/11/07
39	f	Generalized body pains	91	*	126	99	21	10/10/07
67	m	Shortness of breath, weak, lethargic	125	18	99	56	18	10/10/07
19	m	Hypoglycemia	90	16	102	100	17	09/19/07
42	m	Seizure	103	14	106	97	16	10/01/07
20	f	Toothache	75	14	108	99	16	09/16/07

Table 1—Vital signs and descriptive characteristics of patients transported who had a documented SpCO >15%. *data not recorded on prehospital chart (date is in mm/dd/yy format)

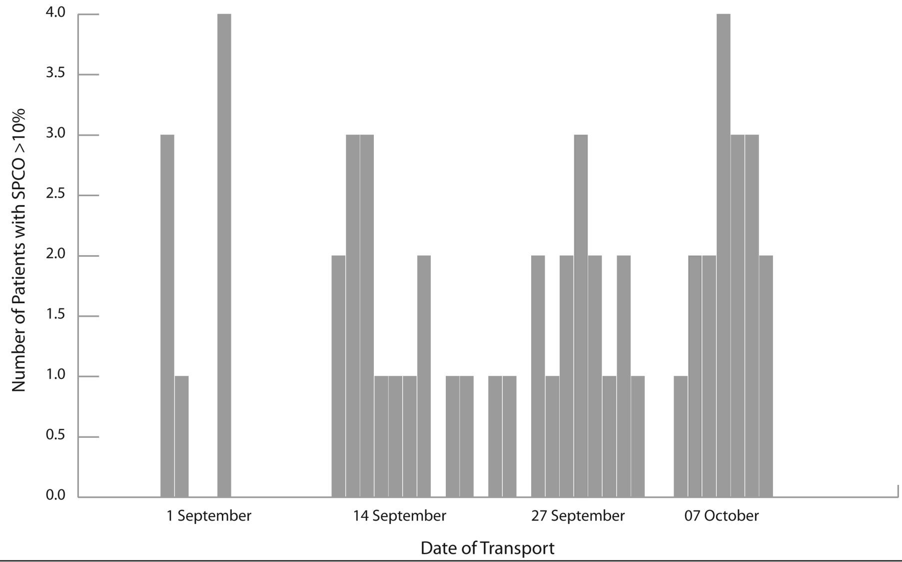

Figure 1—Number of patients with a SpCO >10% transported during the study period

period as shown in Figure 1, with a slight trend toward more patients discovered during the later half of the study period. Males and females had similar SpCO (3.75 ±3.64) vs. 3.57 ±3.67, respectively). There was no correlation between SpCO and heart rate (r_s = 0.081), ventilatory rate (r_s = -0.077), SpO2 (r_s = -0.089) or MAP (r_s = 0.031). An $|r_s|$ ≥0.75 would have indicated a good to very good correlation, while an $|r_s|$ <0.25 indicates little or no relationship.

Of the 11 patients with a SpCO >15%, 10 were transported to a hospital for which the investigators had institutional review board (IRB) approval to review the patient's medical record. Of those 10, none had confirmatory venous carboxyhemoglobin levels. The two patients with an SpCO level of 21% did have a repeat SpCO documented at triage upon arrival to the emergency department. Their repeat levels were 8% and 2%. None of the 10 patients with levels >15% ultimately were diagnosed with and treated for carbon monoxide exposure or toxicity.

Discussion

Management of carbon monoxide toxicity, which can strike any segment of the population at home or at work, should be addressed using a multi-pronged approach. This includes education, source detection using CO monitors, and early identification of patients by screening with a non-invasive device. Education should target at-risk populations and describe common sources of CO and information regarding CO monitors. Source detection should be required in all households and work places through legislation. Finally, screening for CO toxicity should be conducted in healthcare settings with large throughputs, including emergency departments and emergency medical services.

Previous studies demonstrated that CO screening utilizing a non-invasive device is possible and that screening can identify patients with occult CO poisoning, many of whom present to the emergency department for unrelated health concerns. As with many non-invasive screening measurements, such as blood pressure, 12-lead electrocardiogram (ECG) and pulse oximetry, the natural extension to emergency department screening with non-invasive CO oximetry is to use it in the out-of-hospital setting, EMS in particular. Emergency medical services have been active in rapidly adopting new technologies for the prehospital care of patients. Obtaining and transmitting 12-lead ECG in an effort to screen for STEMI, is an example.

As indicated in the current study, CO screening can be conducted in the EMS setting with little investment in education and equipment. Achieving near-100% compliance with any new technology takes time. In this study, close to 40% of all adult patients transported during a six-week period had CO oximetry performed in the field and documented in the EMS chart. The mean CO level is similar to that recorded in the emergency department triage process.[5] The data indicated that most of the patients with recorded high levels of CoHB in the prehospital EMS setting did not have confirmatory levels required during their emergency department evaluation. This may be a result of the lack of education regarding CO toxicity and the relatively new non-invasive technology utilized in the screening process, or due to lack of communication between EMS and emergency department staff. Data obtained from other studies indicate that there are false positive results using the new technology, but the benefit of identifying true positive CO toxic patients outweighs the burden of false positive results.[3] In this cohort, there were at least two patients who had discordant results when a repeat SpCO was obtained, further emphasizing that all positive results obtained with the non-invasive method should be confirmed with a blood carboxyhemoglobin level.

These results suggest that screening for CO toxicity in the EMS setting is possible and may have value in early identification and treatment of CO-poisoned patients. More education is needed to confirm CO toxicity in patients with elevated prehospital SpCO levels. Additional prospective studies of non-invasive CO detection in the EMS setting will be useful in validating the use of this technology for other EMS systems.

Conclusions

Screening for CO toxicity in the EMS setting is possible and may have value for early identification and treatment of CO poisoned patients.

References

1. Suner S, Partridge R, Sucov A, Valente J, Chee K, Hughes A, Jay G: Non-invasive pulse CO-oximetry screening in the emergency department identifies occult carbon monoxide toxicity. *J Emerg Med* 2008;34(4):441–450.
2. Chee KJ, Nilson D, Partridge R, Hughes A, Suner S, Sucov A, Jay G: Finding needles in a haystack: A case series of carbon monoxide poisoning using a new technology in the emergency department. *Clin Toxicol (Phila)* 2008;46(5):461–469.
3. (US) Centers for Disease Control and Prevention (CDC): Unintentional non-fire-related carbon monoxide exposures-United States, 2001–2003. *MMWR* 2005;54:36–39.
4. Walker E: Carbon monoxide poisoning is still an under recognized problem. *BMJ* 1999;319:1082–1083.
5. Kirkpatrick J: Occult carbon monoxide poisoning. *Western J Med* 1987;146:52–56.
6. CDC: Carbon monoxide poisoning after Hurricane Katrina—Alabama, Louisiana, and Mississippi, August–September. *MMWR* 2005;54:996–998.
7. Broder J, Mehrotra A, Tintinalli J: Injuries from the 2002 North Carolina ice storm, and strategies for prevention. *Injury* 2005;36:21–26.
8. Ghim M, Severance HW: Ice storm-related carbon monoxide poisonings in North Carolina: A reminder. *Southern Medical Journal* 2004;97:1060–1065.
9. Keles A, Demircan A, Kurtoglu G: Carbon monoxide poisoning: How many patients do we miss? *Eur J Emerg Med* 2008;15(3):154–157.
10. Cobb N, Etzel RA: Unintetional carbon monoxide-related deaths in the United States, 1979 through 1988. *JAMA* 1991;266:659–663.
11. Ernst A, Zibrak JD: Carbon monoxide poisoning. *N Eng J Med* 1998;339(22):1603–1608.
12. Henry CR, Satron D, Lindgren B, *et al*: Myocardial injury and long-term mortality following moderate to severe carbon monoxide poisoning. *JAMA* 2006;295:398–402.
13. Crawford DM, Hampson NB. Fire and ice: Diagnosis of carbon monoxide poisoning in a remote environment. *Emerg Med J* 2008; 25(4):235–236.
14. Nagano T, Iseki K, Niki T, Suzuki A, Kawamae K. [Experience in employing pulse CO-oximetry]. *Masui* 2008; 57(5):621–623 (Japanese).