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# Non-invasive methods of measuring the carboxyhemoglobin level in pre-hospital procedure

## Nieinwazyjne metody pomiaru karboksyhemoglobiny w postępowaniu przedszpitalnym

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**Keywords**

carbon monoxide, carboxyhemogolin, pehospital treatment, hyperbaric oxygen

**Słowa kluczowe**

tlenek węgla, karboksyhemoglobina, leczenie przedszpitalne, tlenoterapia hiperbaryczna

**Conflict of interest**
**Konflikt interesów**

None
Brak konfliktu interesów

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S u m m a r y

Carbon monoxide is produced as a result of processes of incomplete combustion of coal, wood and many organic substances with the insufficient supply of oxygen. Due to its physical characteristics detecting the presence of carbon monoxide in atmosphere without applying professional devices is impossible. Detectors allowing for confirming the presence of CO are based on three main technologies. These include the chemo-optical technology applying i.a. Gell cells, devices applying metal semiconductors as well as electrochemical detectors. The basic methods of measuring the concentration of carboxyhemoglobin in the blood are laboratory examinations. An alternative are devices used for non-invasive diagnosing of carbon monoxide intoxication of the patient. These methods consist in examining the exhaled air or in placing a sensor on the examined person's finger. Applying devices used for non-invasive determining of carbon monoxide intoxication may be particularly beneficial in pre-hospital care. Reliable pre-hospital measurements may allow for i.a. the direct transportation of a patient to a facility enabling treatment applying a hyperbaric chamber or medical segregation in case of the intoxication of a higher number of patients. The literature on the non-invasive measurements of COHb discusses the reliability of this type of measurements.

S t r e s z c z e n i e

Tlenek węgla powstaje w wyniku procesów niepełnego spalania węgla, drewna i wielu substancji organicznych przy niedostatecznym dopływie tlenu. Ze względu na właściwości fizyczne wykrycie jego obecności w atmosferze bez zastosowania profesjonalnych urządzeń nie jest możliwe. Czujniki pozwalające potwierdzić obecność CO oparte są na trzech głównych technologiach. Zaliczamy do nich technologię chemooptyczną z zastosowaniem m.in. ogniw Gell, urządzenia wykorzystujące półprzewodniki metalu oraz detektory elektrochemiczne. Podstawowymi metodami pomiaru stężenia karboksyhemoglobiny we krwi są badania laboratoryjne. Alternatywą są urządzenia służące do nieinwazyjnego stwierdzania zatrucia tlenkiem węgla u pacjenta. Metody te polegają na zbadaniu powietrza wydychanego lub na umieszczeniu czujnika na palcu osoby badanej. Wykorzystanie urządzeń służących do bezinwazyjnego stwierdzania zatrucia tlenkiem węgla może być szczególnie korzystne w opiece przedszpitalnej. Wiarygodne przedszpitalne pomiary mogą umożliwić m.in. bezpośredni transport pacjenta do ośrodka zajmującego się leczeniem przy wykorzystaniu komory hiperbarycznej czy segregację medyczną w przypadku zatrucia u większej liczby poszkodowanych. W literaturze dotyczącej bezinwazyjnego pomiaru COHb toczy się dyskusja na temat wiarygodności tego typu pomiarów.

Carbon monoxide (CO) which is the by-product of the incomplete combustion of coal has accompanied humanity since they learned to use fire. It may be assumed that in the first homes where fireplaces were situated in the central point and smoke used to vent out through an opening in the roof there was a possibility of generating high concentrations of carbon monoxide which could negatively affect the health and life of the inhabitants (1). The first historical mention of the harmful effect of carbon monoxide is attributed to Aristotle who noticed that coal fumes lead to “a heavy head and death” (2).

Carbon monoxide is produced as a result of processes of incomplete combustion of coal, wood and many organic substances with the insufficient supply of oxygen. During proper combustion coal generates combustion gases containing ca. 1% of carbon monoxide while even 30% of CO may be produced in improper combustion conditions (3). Carbon monoxide is an odorless and colorless gas which does not cause the irritation of respiratory tracts, its molecular weight is 28.01 and its density in reference to that of air is 0.967 (4). In the regulation of the Minister of Health dated 28.09.2005 (Journal of Laws No. 201, item 1674) on hazardous substances it has been classified as an extremely flammable gas and a toxic substance which poses a serious threat to human health. In regulations specifying the acceptable limits of CO concentration the occupational exposure limit has been defined as 23 mg/m$^3$ and the short-term exposure limit (STEL) has been defined as 117 mg/m$^3$. Healthcare room standards define the maximum volume in indoor air as 30 mg/m$^3$ within 24 hours and 100 mg/m$^3$ within 30 minutes (4, 5).

A natural source of carbon monoxide in nature is mainly the oxidation of methane in the atmosphere and the releasing of CO from oceans. Other natural sources are fires of forests and of grasses, volcanoes and storms. A contemporary source of human exposure to the harmful effect of carbon monoxide is primarily industrial activity. The most frequent sources of carbon monoxide in industrial conditions are mines and steelworks. Significant concentrations of CO may occur in boiler rooms, especially those with furnaces fired with culm, in car workshops and garages as well as during using various types of burners. Another source of exposure are heating systems. It is estimated that in Poland over a half of the 6 million households using the gas network possesses gas heaters of flow water. Improper use of heating installations, too tight windows and blocking vent grilles results in the lack of airflow into the rooms and thus incomplete combustion of gas and the production of toxic carbon monoxide concentrations (6). The reason for the occurrence of high carbon monoxide concentrations may also be the meteorological situation when during the formation of the so-called inversions the air movement may favor the injecting of combustion gases into flats. The combustion gases which enter the rooms this way contain not only carbon monoxide but also carbon dioxide and other combustion products possessing a specific smell (7).

Carbon monoxide poses a threat in every concentration and due to the difficulty of identifying it, it is often referred to as a “silent murderer”. According to the statistics of the National Fire Service in the years 2010-2015 in Poland there were over 24 000 carbon monoxide incidents as a result of which over 12 000 people were injured and 477 died (fig. 1).

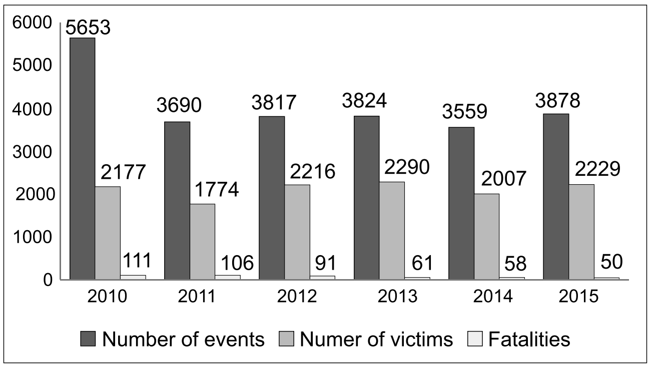


**Fig. 1.** Carbon monoxide intoxications in the years 2010-2015. Elaborated on the basis of data obtained at http://www.straz.gov.pl

Due to the physical properties of carbon monoxide detecting its presence in atmosphere without applying professional devices isn’t possible. The aim of preventive actions based mainly on conducting informative campaigns is applying home CO detectors. They allow for the early detection of the increased concentration of carbon monoxide. Despite of the widespread availability of home detectors their application still isn’t common, that is why in the heating season there are many cases of exposure to the toxicity of CO which generate the need for the interventions of emergency services. Currently detectors allowing for detecting carbon monoxide in atmosphere constitute standard equipment of units of State Fire Service and of Voluntary Fire Departments. They allow for measuring the concentration level of the gas in the inspected room.

Detectors allowing for confirming the presence of CO are based on three main technologies. These include the chemo-optical technology applying i.a. Gell cells, devices applying metal semiconductors as well as electrochemical detectors (8). Regardless of the technology detecting the presence of carbon monoxide is highly significant due to the toxic effect generated in the human organism even by small concentrations of carbon monoxide. The concentration of the gas in atmospheric air causes the occurrence of symptoms which depend on the time which the intoxicated person spent in the toxic environment. A light headache occurs as a result of a 2-3 hour exposure to the concentration ranging from 100 to 200 ppm (0.01-0.02%). With the concentration 400 ppm (0.04%), a strong headache occurs after 60 minutes of inhalation. The gas concentration at the level of 800 ppm (0.08%) causes dizziness, vomiting and convulsions after 45 minutes, and after two hours it leads to a lasting coma. The concentration which is twice as high – 1600 ppm (0.16%) causes a strong headache, vomiting and convulsions within 20 minutes and within 2 hours it leads to death. Higher concentrations cause the occurrence of worrying symptoms already after a few minutes and death occurs within 3-30 minutes of remaining in an atmosphere containing from 3200 ppm (0.32%) to 12 800 ppm (1.28%) of the toxic gas (tab. 1) (9, 10).

**Tab. 1.** Symptoms of carbon monoxide intoxication

| Volumetric concentration of CO in the air | Intoxication symptoms |
|---|---|
| 100-200 ppm (0.01-0.02%) | light headache with the exposure for 2-3 hours |
| 400 ppm (0.04%) | a strong headache beginning after ca. 1 hour of inhaling this concentration |
| 800 ppm (0.08%) | dizziness, vomiting and convulsions after 45 minutes of inhalation; after two hours – a lasting coma |
| 1600 ppm (0.16%) | a strong headache, vomiting, convulsions after 20 minutes, death after 2 h |
| 3200 ppm (0.32%) | an intensive headache and vomiting after 5-10 minutes; death after 30 minutes |
| 6400 ppm (0.64%) | a headache and vomiting after 1-2 minutes; death within less than 20 minutes |
| 12 800 ppm (1.28%) | loss of consciousness after 2-3 inhalations; death after 3 minutes |

Source: http://www.straz.gov.pl/data/other/czujniki_tlenku_wegla.pdf (accessed on 14.03.2017)

Medical Rescue Teams more and more often possess detectors allowing for detecting the presence of carbon monoxide. However such devices are not included in their standard equipment. Such a situations forces members of Medical Rescue Teams to cope with diagnostic difficulties related to non-typical symptoms of CO intoxication which may suggest flu-like sicknesses (headaches and joint pain, nausea), cardiologic sicknesses (arrhythmias, acute coronary syndromes), neurologic sicknesses (headaches and dizziness, behavior disorders, loss of consciousness) (11). The lack of the possibility to detect carbon monoxide is also associated with the risk of the Medical Rescue Team members' exposure to the toxic effects of carbon monoxide which may cause the increasing of the number of intoxicated persons.

The basic method of measuring the blood concentration of carboxyhemoglobin are laboratory tests. The spectrophotometric method applied in biochemical analyzers consists in the measurement of light absorption which is possible for various types of hemoglobin, i.e. oxyhemoglobin, deoxyhemoglobin, carboxyhemoglobin, methemoglobin and sulfhemoglobin. The measurement sum determines the total amount of hemoglobin in the blood simultaneously allowing for determining all of its fractions. One should however keep in mind that the applied spectrophotometers, referred to as oximeters, should have the possibility to measure at least five wavelengths of light. Otherwise in case of carbon monoxide intoxication the result demonstrating the saturation of hemoglobin with oxygen ($SpO_2$) is going to be inflated (12). Similarly a false result ($SpO_2$) in persons intoxicated with carbon monoxide is going to be indicated by standard pulse oximeters performing the measurement using two wavelengths (660 and 990 nm) which makes it impossible to differentiate carboxyhemoglobin (13).

One of the alternatives allowing for the non-invasive examining of the exposure to CO is determining the level of the gas in the exhaled air. This method was first applied in 1948 by a Swedish professor Torgny Sjostrand. The basis for this method is the assumption according to which in the moment of holding one's breath the lungs become a closed vessel (1). Assuming that there is no obstacle on the way of the diffusion of carbon monoxide through the wall of the pulmonary vesicles, the level of carboxyhemoglobin present in the blood of the pulmonary capillaries reaches equilibrium with the COHb level present in the vesicular air (1, 12). Assuming that the measurement is going to be performed in the end-expiratory phase of the breath, the examined person should hold their breath for ca. 15-20 seconds which allows for obtaining the equilibrium of the level of carbon monoxide between the capillary blood and the vesicular air. Next, the studied person should perform a full exhale towards the device using a disposable mouthpiece. After performing the measurement using the electrochemical method the result of the examination is displayed on the screen indicating the level of carbon monoxide (CO) ppm and the percentage of COHb (12). The results of the measurement are automatically saved in the internal memory of the device which allows for the later checking of the data. An advantages of devices such as the Smokerlyzer is their small size allowing for their free transfer to the examined patient. Specially dedicated connectors allow for performing COHb measurements also in intubated patients.

Another method of determining the concentration of carboxyhemoglobin which is based on the non-invasive analysis of various wavelengths of light typical for particular types of hemoglobin has been applied since 2005. Masimo Rainbow sensors are available as a dedicated module, i.a. in Lifepack 15 defibrillators (fig. 2, 3). They allow for performing the measurement by placing the sensor on the examined patient's finger. During the pulsatile blood flow the device performs measurements of the light wavelengths typical for particular types of hemoglobin. The data are transferred to the detector which calculates the content of oxyhemoglobin ($HbO_2$), methemoglobin (MetHb) and carboxyhemoglobin (COHb) (14, 15). In accordance with the manufacturer's description, the device performs measurements of the $SpO_2$ saturation in the range from 50 to 100% with the measurement accuracy ± 3% for the examined range 70-100%. Simultaneously the measurement of carboxyhemoglobin is performed in the range from 0 to 40% with ± 3% accuracy during immobility and of methemoglobin in the range from 0 to 15% with ± 1% accuracy. In the moment of detecting an incorrect level of the examined parameters, the field of the parameter the value of which has been exceeded becomes highlighted in contrasting colors and the message field displays a notification informing about the detecting of an irregularity in the examination (16).

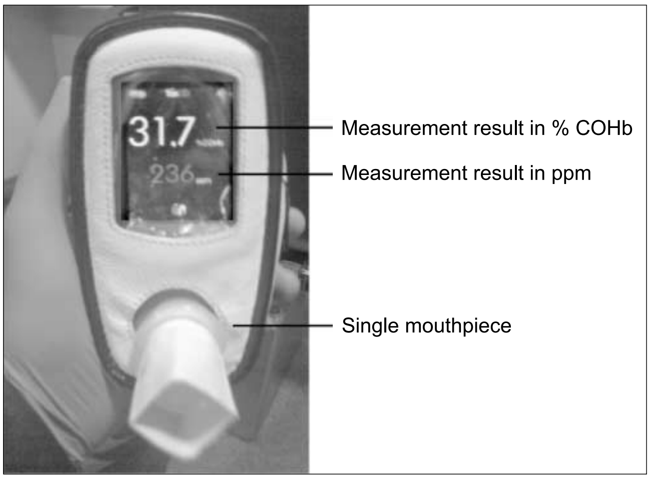


**Fig. 2.** The result of an examination carried out using the ToxCo device

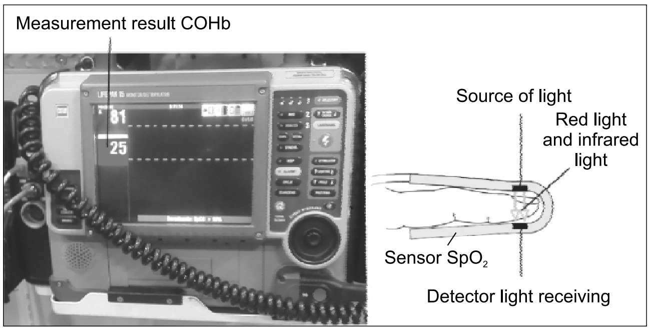


**Fig. 3.** The result of an examination carried out using the Masimo Rainbow sensor

Non-invasive methods of measuring carboxyhemoglobin constitute an alternative in the determining of the level of COHb content in the patient's blood. The literature on the non-invasive measurements of COHb discusses the reliability of this type of measurements. The possibility for reliable pre-hospital determining of the level of carboxyhemoglobin in patients could be associated with numerous benefits. Carbon monoxide intoxication may occur in patients to which the Medical Rescue Team was called due to the deterioration of the health status and who are not suspected of exposure to this substance. Applying a device which additionally offers the possibility of determining the carboxyhemoglobin level during the routine determining of the saturation, it is possible to quickly state that the patient's condition is a result of carbon monoxide intoxication. Owing to this it will be possible to immediately introduce an appropriate treatment method. In their work Suner et al. (14) have described the benefits resulting from the routine determining of the saturation level in over 10 000 patients using a device which additionally offers the possibility to determine the level of carboxyhemoglobin. Thanks to this carbon monoxide intoxication was found in 28 patients while in case of 11 of them it was not suspected that symptoms such as a headache, nausea, vomiting, malaise, dizziness or the condition after losing consciousness were related to carbon monoxide intoxication. Tanks to this the appropriate treatment method was immediately applied in these patients.

Owing to the reliable pre-hospital determining of the level of carboxyhemoglobin it could be possible to omit the necessity of transporting the patient to the nearest Accident & Emergency Department (A&E) for the lab test confirmation of carbon monoxide intoxication and it would be possible to direct the intoxicated person directly to a facility enabling treatment using a hyperbaric chamber. A paper devoted to the analysis of the functioning of one of the American centers for the treatment of patients with carbon monoxide intoxication performed using a hyperbaric chamber presents the method in which carbon monoxide intoxication was found in the patients before arriving to this facility. 1606 out of 1711 patients were referred to the center after prior laboratory determining of the blood carboxyhemoglobin level. In the remaining 105 persons the necessity for hyperbaric oxygen treatment was concluded only basing on a non-invasive measurement. In accordance with the results presented by the author of the paper the average time in which the patients received hyperbaric treatment was by ca. an hour shorter than in the case when it was necessary to confirm the carbon monoxide intoxication using a laboratory blood test (17).

The pre-hospital possibility to diagnose carbon monoxide intoxication may prove to be very valuable in an incident in which a higher number of persons has been injured. The literature includes publications describing evens in which, as a result of a building fire or an inefficient heating system there was the suspicion of the occurrence of a mass carbon monoxide intoxication. Gałązkowski et al. (18) have described an event in which 52 residents and 16 workers of a Nursing Home were at risk of intoxication with this substance.

The operations engaged the participation of i.a. 8 Medical Rescue Teams, 3 helicopters of the Air Emergency Medical Services and a Specialist Medical Rescue Section. Owing to the application of the devices for the non-invasive measurement of the carboxyhemoglobin level which were part of the equipment of the helicopters it was possible to exclude carbon monoxide intoxication among the residents and the workers of the Nursing Home. This allowed for the fast finalizing of the rescue action and thus enabled directing the Medical Rescue and the Air Emergency Medical Services teams to other incidents. This would not be possible if there was a necessity to transport several dozen patients to hospital in order to have their carboxyhemoglobin level determined in lab tests. It would be associated with burdening the functioning of Hospital A&E Departments and would generate significant expenses related i.a. to the diagnostics. In their publication Stasicki et al. present an incident which occurred in one of the tenement houses in Bielsko-Biała. Similarly as in case of the previous situation, devices for the non-invasive determining of the HbCO levels were applied. This allowed for identifying 10 persons intoxicated with carbon monoxide out of the 29 residents. The intoxicated patients were transported to hospital for further diagnostics and treatment (19).

Detecting carbon monoxide intoxication in a patient in pre-hospital conditions may be associated with increasing the safety of the members of the Medical Rescue Team. Diagnosing intoxication in a patient who earlier was not suspected of being intoxicated with CO in the moment of determining the $SpO_2$ provides the team members the possibility to avoid intoxication. Thanks to possessing a device allowing for the non-invasive determining of SpCO in a situation of doubt the team members may confirm or exclude their intoxication with CO. An example is the examination carried out among rescue helicopter crews in Norway. Due to the suspicion that disturbing symptoms such as: fatigue, a headache and nausea may be associated with CO intoxication resulting from inhaling engine exhaust fumes, the members of the crew underwent a non-invasive SpCO determining examination. A carboxyhemoglobin concentration of over 4% was found among 29% of the crew members with the maximum result being 7% (20).

The above mentioned reports may be an argument in favor of standard equipping of Medical Rescue and Air Emergency Medical Services teams with devices used for the non-invasive determining of the carboxyhemoglobin level. On the other hand in the literature it is possible to find reports mentioning the unreliability of this type of equipment. While describing one of the devices of this kind Feiner et al. (21) have mentioned that the reliable determining of the SpCO is possible only when the $SpO_2$ level in the patient is over 85%. Van Ginderdeuren et al. (22) have mentioned that the SpCO level determined incorrectly using non-invasive methods may be due to poor perfusion. Harlan et al. (23) have mentioned that the values of the non-invasive and the laboratory HbCO level may differ significantly. Roth et al. (24) in turn – after analyzing 1578 cases of patients in whom the SpCO level was determined – have stated that determining the SpCO level using an non-invasive method is of "acceptable precision".

Due to the possible numerous benefits related to the pre-hospital application of devices for non-invasive determining of the SpCO level it is necessary to conduct further studies on the possibilities of application and on the effectiveness of such devices.

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received/otrzymano: 02.06.2017
accepted/zaakceptowano: 29.06.2017