Journal of Public Health | pp. 1–10 | doi:10.1093/pubmed/fdab132

Carbon monoxide exposures reported to the UK National Poisons Information Service: a 4-year study

Daniela Gentile[1], Richard Adams[1], Michal Klatka[1], Sally Bradberry[2], Laurence Gray[3], Ruben Thanacoody[4], Gillian Jackson[1], Euan A. Sandilands[1]

[1]National Poisons Information Service (Edinburgh Unit), Royal Infirmary of Edinburgh, Edinburgh EH16 4SA, UK
[2]National Poisons Information Service (Birmingham Unit), City Hospital, Birmingham B18 7QH, UK
[3]National Poisons Information Service (Cardiff Unit), University Hospital Llandough, Penarth CF64 2XX, UK
[4]National Poisons Information Service (Newcastle Unit), Regional Drug and Therapeutics Centre, Newcastle upon Tyne NE2 4AB, UK
Address correspondence to Daniela Gentile, E-mail: daniela.gentile@nhslothian.scot.nhs.uk.

ABSTRACT

Background Unintentional carbon monoxide (CO) poisoning poses a public health challenge. The UK National Poisons Information Service (NPIS) provides advice to healthcare professionals via the online database, TOXBASE®, and a 24-hour telephone line. Our aim was to analyse all CO-related enquiries to the NPIS.

Methods We analysed enquiries regarding unintentional CO exposure (1st July 2015-30th June 2019). Information on patient demographics, CO source and location, clinical features and poisoning severity was collected from telephone enquiries and TOXBASE accesses.

Results 2970 unintentional non-fire-related CO exposures were reported. Exposures occurred commonly in the home (60%) with faulty boilers frequently implicated (27.4%). Although five fatalities were reported, 68.7% of patients experienced no or minor symptoms only (headache most frequently reported). Despite being the gold standard measurement, blood carboxyhaemoglobin concentration was only recorded in 25.6% patients, with no statistically significant correlation with severity.

Conclusions Unintentional CO exposures in the UK commonly occur in domestic settings and although are generally of low severity, fatalities continue to occur. Carboxyhaemoglobin measurement is important to confirm exposure but further work is required to assess its validity as a prognostic indicator in CO exposure. Public health policy should continue to focus on raising awareness of the dangers of CO.

Keywords carbon monoxide, CO, carboxyhaemoglobin, poisoning, TOXBASE

Introduction

Carbon monoxide (CO) is a colourless, odourless, non-irritant gas produced following the incomplete combustion of carbon-containing compounds. Common sources include house fires, defective generators or heating appliances and vehicle exhaust emissions.[1] CO is also present in cigarette smoke and produced endogenously through the breakdown of haem.[2,3] Exposure to CO may be acute or chronic and can occur either unintentionally or intentionally through an act of self-harm.[2] Unintentional exposures may be further subdivided into those related to fires (where additional toxicity such as cyanide may contribute) and non-fire related CO exposures. Unintentional non-fire related CO exposures pose a serious public health challenge and as such are the primary focus of this study. Patients are often unaware of the presence of the poisonous gas even after they begin to experience symptoms. Public health policy is focused on raising awareness of this hidden danger while identifying and eliminating potential sources of CO.

The epidemiology of CO exposures is difficult to elucidate accurately, in part due to the complexity of how exposures are categorized. The World Health Organisation (WHO) reported a total of 140 490 CO-related deaths across 28 European member states between 1980 and 2008 (annual death rate of 2.2/100 000).[4] A study in the USA (1999–2012) reported 438 deaths/annum from unintentional

Daniela Gentile PhD, Specialist in Poisons Information
Richard Adams, Assistant Information Services Manager
Michal Klatka, Project Assistant
Bradberry Sally, Consultant Clinical Toxicologist
Gray Laurence, Consultant Clinical Toxicologist
Thanacoody Ruben, Consultant Clinical Toxicologist
Gillian Jackson PhD, Information Services Manager
Euan A. Sandilands, Consultant Clinical Toxicologist

non-fire related CO poisoning.[5] In England and Wales, fatalities associated with unintentional non-fire related CO exposures have declined over recent decades from 3.37/100 000 in 1979 to 0.44 deaths/100 000 in 2012.[6] In Scotland, 209 CO-related deaths were reported between 2007 and 2016[1], although this figure included both fire-related and non-fire related exposures. In addition to mortality data, significant morbidity is associated with CO, with an estimated 4000 annual Emergency Department (ED) presentations[7] and more than 200 hospital admissions in England alone (2002–2016).[8]

Following exposure, CO is absorbed through the lungs and combines preferentially with haemoglobin (Hb) in red blood cells to produce carboxyhaemoglobin (COHb), reducing oxygen delivery to vital tissues.[8,9] CO also binds to myoglobin in cardiac and skeletal muscle and cytochrome oxidases, impairing cellular utilization of oxygen[9,10,11] The diagnosis of CO poisoning depends on confirming a history of exposure, identifying symptoms consistent with CO poisoning, and demonstrating an elevated COHb concentration. A variety of methods can be used to measure this including exhaled breath testing, fingertip pulse CO-oximetry and, the gold-standard method of blood sampling with spectrophotometrical measurement (defined as a percentage of total haemoglobin (COHb%)).[12] The diagnosis, however, is not always straightforward as symptoms are varied and non-specific, may be affected by age and co-morbidity, and correlate poorly with COHb%.[2,13] Additionally, COHb% may be difficult to interpret as it is dependent on the atmospheric concentration of CO at the scene of exposure, activity levels of the patient following exposure, whether the patient is a smoker or has been in an enclosed environment with smokers. Furthermore, the half-life of COHb% is reduced from ∼5 h when breathing air to 80-minutes following administration of 100% oxygen, therefore, the timing and administration of any supplemental oxygen will further complicate COHb% interpretation.[2,14] Finally, it has been suggested that as individual doctors encounter CO poisoning so infrequently, CO exposure may not be immediately considered at the time of presentation with any further delays having implications for further variations in COHb% measurements.[2]

The UK National Poisons Information Service (NPIS) provides information and evidence-based management advice to healthcare professionals through the online poisons database TOXBASE® and a national 24-h telephone advice service, staffed by poisons information specialists and supported by consultant clinical toxicologists. This service is used by front line health professionals when managing poisoned patients, including those exposed to CO. It is therefore uniquely positioned to gather data from healthcare professionals across the UK to help to understand our experience of CO poisoning in the UK. Through a greater understanding of the scale of the problem, symptoms reported and sources of CO, recognition and management of these patients may be improved to allow targeted treatment towards those most in need while preventing unnecessary hospital admissions.

Methods

We analyzed all CO-related enquiries to the NPIS over a 4-year period between 01 July 2015 and 30 June 2019. Telephone enquiries to the NPIS are routinely recorded in the UK Poisons Information Database. Enquiries were received from hospitals, primary care, NHS triage services (e.g. NHS 111/Direct/24) and the ambulance service. Enquiries specifically relating to CO exposure during the study period were extracted using the search terms: 'carbon monoxide', 'fire', 'fumes' or 'smoke' to ensure all potential CO exposures were identified. Data collected included patient demographics, location and source of exposure, symptoms reported, exposure severity and COHb% concentration where available. In addition, accesses to TOXBASE (defined as a user logging onto TOXBASE and viewing the CO page) were interrogated during the 4-year period. An online questionnaire was attached to the TOXBASE CO management page which appeared on the screen at the point of access, inviting users to anonymously provide relevant details about the exposure as they were treating the patient. Follow up questionnaires were sent to all enquirers in an effort to capture as much data as possible as some information may not have been available at the time of the initial enquiry. Enquiries where the CO exposure was fire related (e.g. house fire) or intentional were excluded.

The severity of each exposure was assessed according to the Poison Severity Score (PSS).[15] This is a standardized scale for grading the severity of poisoning episodes according to system-based symptoms reported: no symptoms (PSS 0), mild and transient symptoms (PSS 1), moderate symptoms (PSS 2), severe or life-threatening symptoms (PSS 3) and a fatal outcome (PSS 4). A maximum PSS was applied by the poison information specialist at the time of each enquiry. For TOXBASE accesses, the PSS was applied by the lead author after the clinical information was provided.

Statistical analyses were undertaken using two-tailed Fisher's exact test and Spearman correlation test in GraphPad Prism Version 7.02 (GraphPad software, La Jolla, CA, USA). This study did not require approval by a UK Research Ethics Committee as the UK Health Research Authority has declared

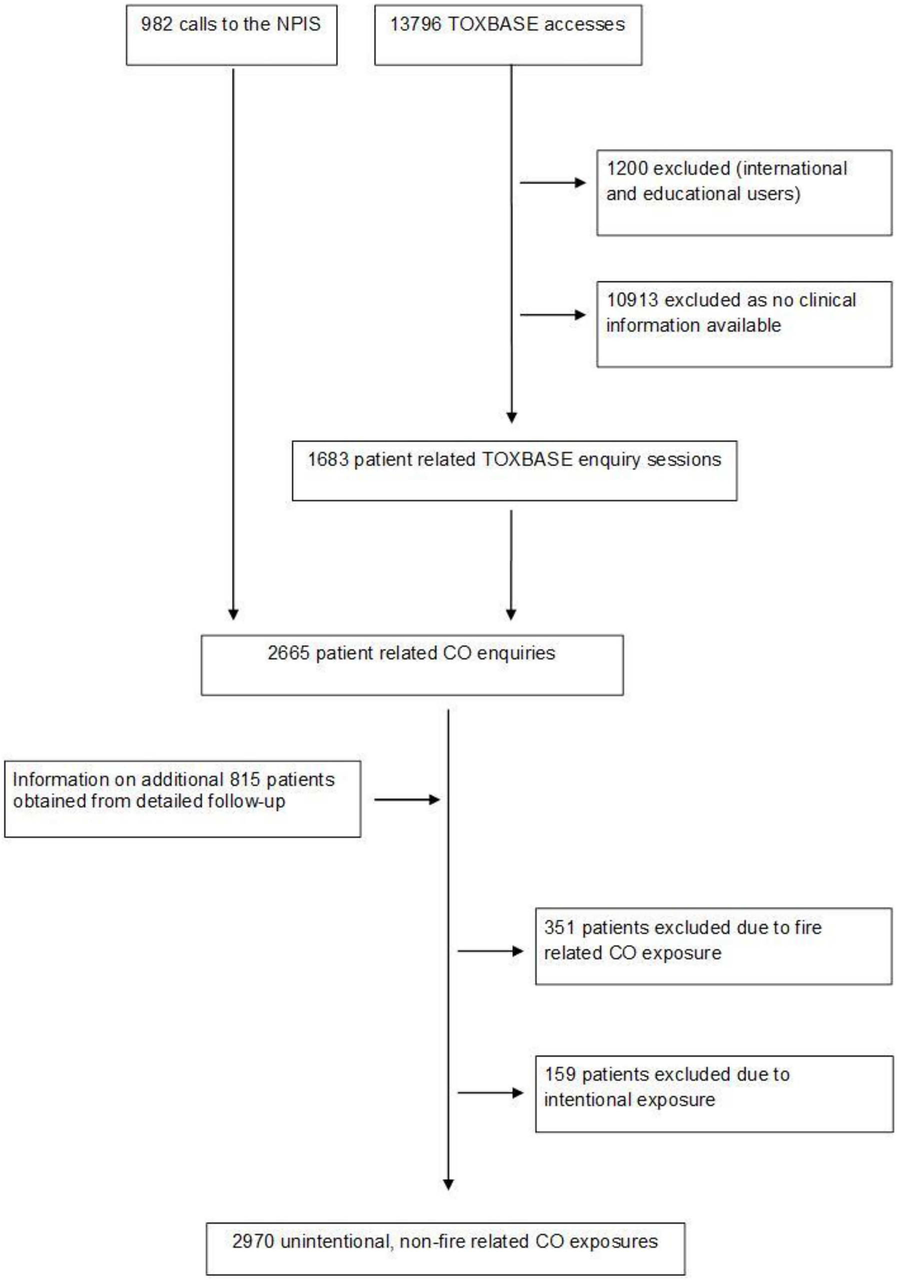

Fig. 1 Patient-related queries regarding carbon monoxide to the NPIS.

that ethical approval is not needed for research studies using information collected routinely by any UK administration as part of usual clinical care, provided this information is passed to the researchers in a fully anonymized format.

Results

During the 4-year study period, there were 982 telephone enquiries regarding CO exposures and 13 796 TOXBASE accesses to the CO management page (Fig. 1). TOXBASE accesses were excluded from further analysis if they were from international users or for educational purposes (1200, 8.1%), or where no clinical information was provided (10 913, 73.8%). This left 1683 patient-related TOXBASE accesses and 982 telephone enquiries, giving a total of 2665 (18.0%) CO-related NPIS enquiries. Clinical information from follow up questionnaires yielded information about an additional 815 patients (e.g. where the initial enquiry was logged as a single patient but it related to a multiple occupancy household involving more than one patient exposure). Three hundred and fifty one (2.3%) cases were excluded as the source of CO was secondary to fire exposure, and 159 (1.1%) exposures excluded as intentional self-harm exposures. This resulted in a study group of 2970 unintentional non-fire related exposures.

The source of enquiry differed according to whether it was a telephone or TOXBASE enquiry. Enquires received by telephone were from NHS telephone services (332, 11.2%), hospitals (309, 10.4%), primary care (242, 8.1%) and the ambulance service (99, 3.3%) while TOXBASE accesses were from NHS telephone services (193, 6.5%), hospitals (1552, 52.3%), primary care (185, 6.2%) and the ambulance service (58, 2.0%).

Patient demographics

Of the 2970 unintentional non-fire related exposures, 1026 (34.5%) were female and 728 (24.5%) were male; gender was not recorded in 1216 (40.9%) cases (Table 1). Seventy-three patients were reported to be pregnant at the time of exposure. In children, those aged 0–9 years (400; 13.5%) were involved in a significantly greater proportion of CO exposures than those aged 10–19 years (196; 6.6%; $P < 0.0001$). In adults, the largest number of exposures occurred in patients aged 20–29 (370; 12.5%) and 30–39 years (390; 13.1%). These were significantly greater than those age $\geq$ 40 years ($P < 0.01$, Table 1).

Time and location of the exposure and source of carbon monoxide

Seasonal variation was demonstrated in the frequency of enquiries with more exposures occurring during colder winter months (Fig. 2). The highest monthly number of cases recorded (127) was during November 2016. The location of exposures was recorded in 2274 (76.6%) cases, with the vast majority in the home ($P < 0.0001$ compared to other locations, Table 1). The source of CO was identified in 1910 (64.3%) cases. Faulty boilers were significantly more common than other identified sources (813; 27.4%; $P < 0.0001$ compared to all other sources).

Symptoms reported and poison severity score

There were 827 (27.9%) asymptomatic patients. A wide range of clinical features were reported with many patients reporting multiple symptoms (Table 2). Clinical features involving the central nervous system (CNS) were most common with headache being the most frequently reported symptom ($P < 0.0001$). The majority of patients (2040 (68.7%)) experienced no symptoms (PSS 0) or mild symptoms (PSS 1) only, with 141 exposures (4.8%) being recorded as moderate (PSS 2), and 33 (1.1%) reported as severe (PSS 3).

Five fatalities (0.2%; PSS 4) related to unintentional non-fire related CO-exposures were reported. Four of these exposures occurred in a domestic setting and one in commercial premises. Four patients died before reaching hospital. Although no confirmatory COHb% was available for these patients, CO was considered as the cause of death since other patients at the scene reported symptoms consistent with CO poisoning and themselves had documented COHb% between 17 and 38%. The final patient died on arrival to hospital with a recorded COHb% of 21.9%.

Of the 73 pregnant patients, the majority (67, 91.8%) reported no symptoms or minor symptoms only. One pregnant patient had symptoms of moderate severity (palpitations and dyspnoea), while for the remaining five patients no information about the symptoms was available.

Carboxyhaemoglobin concentration

Carboxyhaemoglobin concentration was reported in 889 (30.0%) cases (761 blood, 63 CO pulse oximetry, 65 CO exhaled air). As the gold standard method, our analysis focused on blood sampling which was reported in 761 patients (25.6%). Analysis of PSS according to median COHb% values (Table 2) suggests a positive correlation ($r = 0.9$, Spearman), however, this was not statistically significant ($P = 0.08$).

Carbon monoxide detector

Information about activation of CO detectors during each exposure was not specifically collected. However, in 596 cases (20.1% of the total study group), it was reported that activation of a CO detector prompted the patient to seek medical attention. In the majority of these cases (514 (86.2%), the patients had no symptoms or minor symptoms, whilst nine patients (1.5%) experienced symptoms of moderate severity. Symptoms were unknown in 73 patients (12.2%).

Discussion

Main findings of this study

This study presents data on a total of 2970 enquiries to the NPIS related to unintentional non-fire related CO exposures between July 2015 and June 2019. These were most often reported during winter months, involved all age groups but most frequently children and adults aged 20–39 years, and commonly occurred in the home as a result of faulty boilers. While the majority of cases were of low severity, five fatalities were reported.

Table 1 Patient demographics, location and source of unintentional non-fire related CO exposures

Demographics		*N*	%
Gender	Male	728	24.5
	Female	1026	34.5
	Gender unknown	1216	40.9
Age (years)			
Children	0–9	400	13.5[c]
	10–19	196	6.6
Adults	20–29	370	12.5[d]
	30–39	390	13.1[d]
	40–49	309	10.4
	50–59	232	7.8
	60–69	106	3.6
	70+	152	5.1
	Age unknown	815	27.4
Location		*N*	%
	Home	1777	59.8[c]
	Business – non-office	153	5.2
	Car	127	4.3
	Business – office	39	1.3
	Caravan	32	1.1
	Public space	30	1.0
	Garage	27	0.9
	Leisure accommodation	18	0.6
	Tent	6	0.2
	Boat	4	0.1
	Other[a]	61	2.1
	Unknown	696	23.4
	Total	2970	—
Source		*N*	%
	Boiler	813	27.4[c]
	Gas appliance (excluding boilers)	218	7.3
	Vehicle exhaust	204	6.9
	Wood/coal fire burner	148	5.0
	Cooker	89	3.0
	Gas heater	61	2.1
	Industrial/work appliances	60	2.0
	Gas fire	53	1.8
	Generator exhaust	33	1.1
	BBQ	26	0.9
	Camping stoves	21	0.7
	Other[b]	184	6.2
	Unknown	1060	35.7
	Total	2970	—

[a]e.g. Restaurant kitchen, industrial site, school (<0.1%). In 15 cases (0.5%), location was reported as other but no further details supplied.
[b]e.g. Fire pit, scuba diving tank, paint stripper, shisha (<0.5%). In 67 cases (2.3%), source was reported as other but no further details supplied.
[c]$P < 0.0001$, compared to other variables in the group.
[d]$P < 0.001$, compared to other variables in the group.

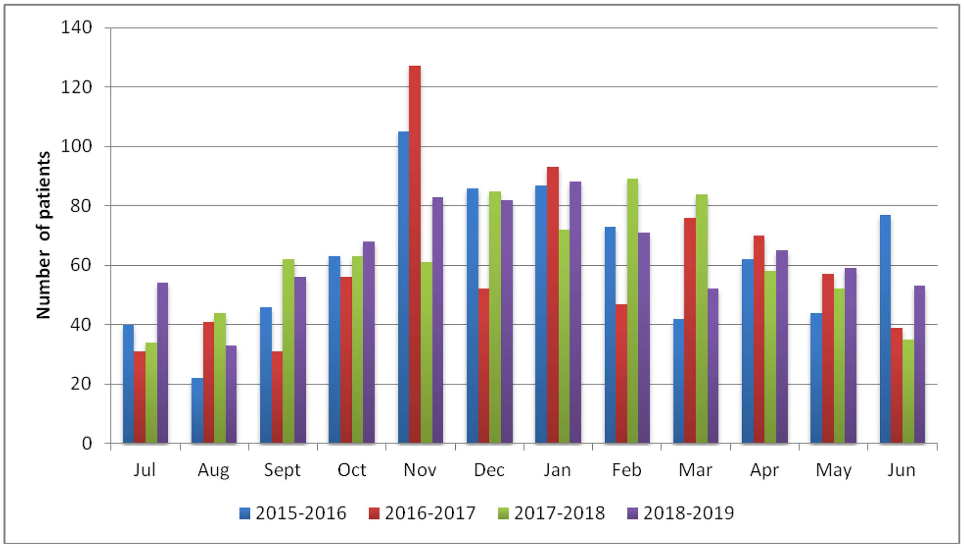

Fig. 2 Unintentional non-fire related CO exposures according to month/year.

Defining the true epidemiology of CO exposures is challenging with variation in how data is collected, categorized and recorded. Hospital Episode Statistics (HES) data (2015–2018) reported 208 admissions/year due to accidental CO exposures in the UK[16–19], while McCann *et al*.[7] reported an estimated 4000 ED presentations annually. We have presented data on 2970 NPIS enquiries (~740/year) which represents information from healthcare professionals treating CO poisoned patients in all four UK nations. As such the data presented here includes information on clinical parameters including biomarkers, poisoning severity and the source and location of the exposure, not traditionally included in other epidemiological studies using coded hospital data. Furthermore, in addition to admitted patients, the current study includes patients presenting to EDs who are discharged without admission and also those assessed in the community.

We reported five fatalities over the 4-year study period. This is lower than expected when compared to national mortality data which demonstrated 18 deaths from unintentional CO exposures in 2018, a reduction from 32 deaths reported in 2015[20–28]. Our data may underestimate mortality figures as it only represents those cases where health professionals contacted the NPIS for clinical management advice. Exposures managed without NPIS involvement and indeed any out of hospital deaths are not included.

The seasonal variation in exposures supports previous studies and is likely due to an increased use of gas appliances in colder temperatures[29–31] Children and the elderly have previously been reported to be more commonly implicated.[29] While it is possible that these patient groups are at a particular risk from CO, they are also more likely to spend longer periods of time indoors, particularly in the winter and, should a CO leak occur, be less able to recognize and seek help to reduce exposure. In the current study we demonstrated a significantly greater number of CO exposures in younger children (<10 years) compared to their older counterparts (10–19 years). In contrast, fewer exposures were reported in patients over the age of 60 years. It is unclear why fewer exposures were reported in older patients in our study but may reflect the methodology. Older patients are perhaps more likely to be admitted to hospital following an episode of CO exposure and therefore analysis of admission data may demonstrate a greater proportion of elderly patients compared to data including exposures not requiring admission.

The majority of exposures reported were of low severity and associated with no symptoms or mild symptoms only. Where clinical features were reported these were often varied and non-specific, highlighting the diagnostic challenge facing health professionals. As previously shown, symptoms reported most often involved the CNS with headache being most common.[11,32]

Raised COHb% is necessary to confirm exposure so that appropriate treatment may be instigated, and the source of CO investigated. Clinical interpretation of the COHb% concentration is complex as it may be affected by patient-related factors such as smoking status and co-morbidity. Cigarette smoking can significantly impact COHb% with baseline concentrations considered to be ≥2.5% in non-smokers and ≥5% in smokers.[14] Environmental factors (e.g. atmospheric concentration of CO at the scene, duration

Table 2 Clinical outcomes reported following unintentional non-fire related CO exposures

Body system	Clinical features[a]	*N*	%
	Asymptomatic	827	27.9
	Unknown	712	24.0
CNS	Headache	712	24.0
	Nausea	332	11.1
	Lethargy/fatigue/malaise	327	11.0
	Dizzy, faint, lightheaded	302	10.2
	Somnolence, drowsy	107	3.6
	Confusion/concentration impaired	80	2.7
	Coma, unconsciousness	28	0.9
	Amnesia	21	0.7
GI	Vomiting	121	4.1
	GI upset	79	2.7
Respiratory	Cough	64	2.2
	Dyspnoea	57	1.9
	Chest pain	47	1.6
	Mouth/throat pain/pharyngitis	36	1.2
	Flu-like symptoms	29	1.0
	Wheeze	20	0.7
Cardiovascular	Palpitations	28	0.9
musculoskeletal	Muscle weakness	26	0.9
eye	Eye irritation/blurred vision	28	0.9
Poisoning severity	***N*[b]**	**COHb%**	
		Median	Min–Max; [IQR][c]
None (PSS 0)	190	2.4	0–33.0; [1.1–4.5]
Minor (PSS 1)	368	2.80	0–45.0; [1.2–6.4]
Moderate (PSS 2)	72	7.8	0–36.4; [2.9–20.2]
Severe (PSS 3)	26	24.4	2.5–40.0; [18.5–29.1]
Fatal (PSS 4)	1	21.9	NA

[a]Note: clinical features reported where frequency was ≥20. Due to multiple symptoms, the sum of the percentages will be >100% when asymptomatic and unknown cases are included.

[b]Excludes 104 cases where PSS was unknown.

[c]IQR: interquartile range.

of exposure, time since removal from source and oxygen administration) also influence COHb%[14]. In the current study, blood COHb% concentration was reported in only 25.6% of patients. The low reporting of this biomarker may be related to the large proportion of asymptomatic patients as clinicians may have felt an invasive confirmatory test in an otherwise well patient was unnecessary. It should also be noted that smoking status was only available in 24.3% of patients making it difficult to ascertain the effect of this variable. Furthermore, limited information was available about the specific timing of the COHb% measurement with respect to the time of exposure and indeed whether supplemental oxygen was administered pre- or in hospital. In our study, COHb% values of greater than 10 and 20% were reported in 7.4 and 2.1% of asymptomatic patients respectively, while 37.5% of patients with moderate toxicity demonstrated a COHb% of > 5%. This highlights the challenge of interpreting COHb% as a marker of severity as opposed to simply confirmation of exposure. It is important that clinicians are aware of this as a low COHb% could be falsely reassuring and result in patients being sent home, potentially to be re-exposed to CO.

The majority of exposures occurred within the home were most commonly associated with faulty boilers. This is consistent with previously published UK data.[29,33] Public health policy is aimed at increasing awareness of the hidden dangers associated with CO poisoning through the promotion of CO detectors.[34] However, there are differences between constituent nations of the UK with respect to the installation of CO detectors[35–39]. Information about CO detectors was not routinely collected during NPIS enquiries. Nevertheless, enquirers voluntarily provided information about activation of a CO detector in ∼20% of cases. The vast majority of these patients reported no symptoms or minor symptoms, with only nine patients reporting clinical features of moderate toxicity.

What is already known on this topic?

CO poisoning is a major public health concern.[40] Epidemiological data vary between countries, in part due to reporting differences; therefore, determining the true scale of the problem is challenging. Unintentional non-fire related CO exposures pose a particular public health challenge as patients are often unaware of the presence of CO even after they begin to experience symptoms. Public health policy is focused on raising awareness of this hidden danger while identifying and eliminating potential sources of CO.

What this study adds?

This study presents data on 2970 enquiries to the UK NPIS over a 4-year study period regarding unintentional non-fire related CO exposures. Enquiries to the NPIS were received from frontline healthcare professionals treating CO-exposed patients across the UK both in and out of hospital. The data therefore include information on patients admitted to hospital and those treated in the community and EDs (without admission). Information on clinical parameters, poisoning severity and COHb% concentration allows a more detailed assessment of the clinical burden of this problem.

We have demonstrated that exposures were more common in winter months and frequently occurred in the home as a result of faulty boilers. An increased incidence of exposures was reported in children ≤ 9 years and adults aged 20–39 years. In contrast to previously reported data[29], the incidence of exposures in the elderly in our study was lower. Blood COHb% was reported in 761 patients (25.6% of exposures). While the data suggest a positive correlation between COHb% and poisoning severity, this was not statistically significant. Further work is required to elucidate the variables that may affect COHb% values and assess the validity of COHb% as a prognostic marker. Through a greater understanding of any potential correlation between COHb% and poisoning severity, we hope to develop targeted treatment strategies aimed at those most at risk.

Limitations of this study

There are a number of limitations associated with this study. Similar to other poison centre studies, these data represent only cases where health professionals have contacted the NPIS for clinical management advice and therefore may underestimate the true incidence of CO poisoning in the UK. Minor exposures where the patient does not present for assessment or a clinician does not require NPIS advice are not included. Similarly, severe exposures resulting in out of hospital deaths would not be included. The quality of the data is reliant on the information provided by the treating clinicians whose primary concern at the time of the enquiry was the patient in their care. Finally, no data were available on the long term follow-up of patients. A more detailed study including outcome data is required to improve our knowledge of the true effect of CO poisoning.

Disclosure statement

The authors declared no potential conflicts of interest. The authors alone are responsible for the content and writing of this article.

Funding

This work was supported by the Gas Safety Trust who awarded a grant to the UK NPIS to undertake studies on the epidemiology and toxicity of carbon monoxide exposures in the UK.

References

1 Lisbona CF, Hamnett HJ. Epidemiological study of carbon monoxide deaths in Scotland 2007-2016. *J Forensic Sci* 2018;**63**(**6**):1776–82.

2 Wright J. Chronic and occult carbon monoxide poisoning: we don't know what we're missing. *Emerg Med J* 2002;**19**(**5**):386–90.

3 Gozubuyuk AA, Dag H, Kacar A *et al.* Epidemiology, pathophysiology, clinical evaluation, and treatment of carbon monoxide poisoning in child, infant, and fetus. *North Clin Istanb* 2017;**4**(**1**):100–7.

4 Braubach M, Algoet A, Beaton M *et al.* Mortality associated with exposure to carbon monoxide in WHO European member states. *Indoor Air* 2013;**23**:115–25.

5 Sircar K, Clower J, Shin MK *et al.* Carbon monoxide poisoning deaths in the United States, 1999 to 2012. *Am J Emerg Med* 2015;**33**(**9**):1140–5.

6 Fisher DS, Leonardi G, Flanagan RJ. Fatal unintentional non-fire-related carbon monoxide poisoning: England and Wales, 1979-2012. *Clin Toxicol (Phila)* 2014;**52**:166–70.

7 McCann LJ, Close R, Staines L *et al.* Indoor carbon monoxide: a case study in England for detection and interventions to reduce population exposure. *J Environ Public Health* 2013;**2013**:735952.

8 Roca-Barceló A, Crabbe H, Ghosh R *et al.* Temporal trends and demographic risk factors for hospital admissions due to carbon monoxide poisoning in England. *Prev Med* 2020;**136**:106104.

9 Bateman DN. Carbon monoxide. *Medicine* 2012;**40**:115–6.

10 Varon J, Marik PE, Fromm RE Jr, Gueler A. Carbon monoxide poisoning: a review for clinicians. *J Emerg Med* 1999;**17**:87–93.

11 Rose JJ, Wang L, Xu Q *et al.* Carbon monoxide poisoning: pathogenesis, management, and future directions of therapy. *Am J Respir Crit Care Med* 2017;**195**(**5**):596–606.

12 Hampson NB, Piantadosi CA, Thom SR, Weaver LK. Practice recommendations in the diagnosis, management, and prevention of carbon monoxide poisoning. *Am J Respir Crit Care Med* 2012;**186**: 1095–101.

13 Smollin C, Olson K. Carbon monoxide poisoning (acute). *BMJ Clin Evid* 2010;**2010**:pii: 2103 Review.

14 Clarke S, Keshishian C, Murray V *et al.* Screening for carbon monoxide exposure in selected patient groups attending rural and urban emergency departments in England: a prospective observational study. *BMJ Open* 2012;**2**(**6**):pii: e000877.

15 Persson HE, Sjöberg GK, Haines JA, Pronczuk de Garbino J. Poisoning severity score. Grading of acute poisoning. *J Toxicol Clin Toxicol* 1998;**36**(**205**):213.

16 Data and Integration Directorate, *NHS Digital User requested data* September 2020 (unpublished).

17 Information Services Division, *NHS National Services Scotland User requested data* March 2020 (unpublished).

18 Information Services Division, *NHS Wales Informatics Services User requested data* March 2020 (unpublished).

19 DoH Research and Statistics, *Information & Analysis Directorate, Northern Ireland User requested data* February 2020 (unpublished).

20 Office for National Statistics. *Number of Deaths from Accidental Poisoning by Carbon Monoxide, England and Wales, Deaths Registered in 2015 to 2016*, https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/adhocs/007476numberofdeathsfromaccidentalpoisoningbycarbonmonoxideenglandandwalesdeathsregisteredin2015to2016 (accessed January 2020).

21 Office for National Statistics. *Number of Deaths from Accidental Poisoning by Carbon Monoxide, England and Wales, Deaths Registered in 2017*, https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/adhocs/009122numberofdeathsfromaccidentalpoisoningbycarbonmonoxideenglandandwalesdeathsregisteredin2017 (accessed January 2020).

22 Office for National Statistics. *Number of Deaths from Accidental Poisoning by Carbon Monoxide, England and Wales, Deaths Registered in 2018*, https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/adhocs/10814numberofdeathsfromaccidentalpoisoningbycarbonmonoxideenglandandwalesdeathsregisteredin2018 (accessed January 2020).

23 National Records Scotland. *Vital Events Reference Tables 2015, Section 6: Deaths – Causes (Table 6.12 Deaths from Poisoning, by Sex and Cause, Scotland, 2015)*, https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/vital-events/general-publications/vital-events-reference-tables/2015/section-6-deaths-causes (accessed January 2020).

24 National Records Scotland. *Vital Events Reference Tables 2016, Section 6: Deaths – Causes (Table 6.12 Deaths from Poisoning, by Sex and Cause, Scotland, 2016)*, https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/vital-events/general-publications/vital-events-reference-tables/2016/section-6-death-causes (accessed January 2020).

25 National Records Scotland. *Vital Events Reference Tables 2017, Section 6: Deaths – Causes (Table 6.12 Deaths from Poisoning, by Sex and Cause, Scotland, 2017)*, https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/vital-events/general-publications/vital-events-reference-tables/2017/section-6-death-causes (accessed January 2020).

26 National Records Scotland. *Vital Events Reference Tables 2018, Section 6: Deaths – Causes (Table 6.12 Deaths from Poisoning, by Sex and Cause, Scotland, 2018)*, https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/vital-events/general-publications/vital-events-reference-tables/2018/section-6-death-causes (accessed January 2020).

27 Northern Ireland Statistics and Research Agency (NISRA). *User Requested Deaths Data, Carbon Monoxide Deaths by Age, LGD and Cause of Death 2011–2016*, https://www.nisra.gov.uk/publications/user-requested-deaths-data (accessed January 2020).

28 Northern Ireland Statistics and Research Agency(NISRA). *User Requested Deaths Data, Carbon Monoxide Deaths by Cause of Death 2017–2018*, February 2020 (unpublished data).

29 Ghosh RE, Close R, McCann LJ *et al.* Analysis of hospital admissions due to accidental non-fire-related carbon monoxide poisoning in England, between 2001 and 2010. *J Public Health (Oxf)* 2016;**38**: 76–83.

30 Lavigne E, Weichenthal S, Wong J *et al.* Mortality and hospital admission rates for unintentional nonfire-related carbon monoxide poisoning across Canada: a trend analysis. *CMAJ Open* 2015;**3**: E223–30.

31 Can G, Sayılı U, Aksu Sayman Ö *et al.* Mapping of carbon monoxide related death risk in Turkey: a ten-year analysis based on news agency records. *BMC Public Health* 2019;**19**(**1**):9.

32 Hullin T, Aboab J, Desseaux K *et al.* Correlation between clinical severity and different non-invasive measurements of carbon monoxide concentration: a population study. *PLoS One* 2017;**12**(**3**):e0174672.

33 Wilson RC, Saunders PJ, Smith G. An epidemiological study of acute carbon monoxide poisoning in the west midlands. *Occup Environ Med* 1998;**55**(**11**):723–8.

34 All Party Parliamentary Carbonmonoxide Group, *From Awareness to Action* 2015. https://www.policyconnect.org.uk/appcog/research/inquiry-behavioural-insights (accessed January 2020).

35 The Smoke and Carbon Monoxide Alarm (England) Regulations 2015 http://www.legislation.gov.uk/uksi/2015/1693/contents/made (accessed May 2019).

36 *Part J - Combustion appliances and fuel storage systems* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/468872/ADJ_LOCKED.pdf (Accessed May 2019).

37 Welsh Government. *Rent Smart Wales: Code of Practice*. https://gov.wales/rent-smart-wales-code-practice (accessed August 2019).

38 Scottish Government. *Carbon Monoxide Alarms in Private Rented Properties: Guidance 2016*, https://www.gov.scot/publications/carbon-monoxide-alarms-in-private-rented-properties-guidance/ (accessed Feb 2019).

39 HSENI 2013. *Carbon Monoxide Detectors*. https://www.hseni.gov.uk/publications/carbon-monoxide-detectors (accessed Feb 2019).

40 Raub JA, Mathieu-Nolf M, Hampson NB, Thom SR. Carbon monoxide poisoning–a public health perspective. *Toxicology* 2000;**145**(**1**): 1–14.