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All-Party Parliamentary carbonmonoxide Group

CARBON MONOXIDE POISONING: SAVING LIVES, ADVANCING TREATMENT

A Call for Action Across the Healthcare Sector

Compiled by Healthcare Professionals

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2. FOREWORD

Carbon monoxide (CO) is a silent killer. It is a colourless, odourless and tasteless poisonous gas produced by the incomplete combustion of carbon-based fuels, such as gas, oil, biomass and wood. According to Public Health England, every year over 30 people in England and Wales lose their lives to accidental, non-fire related CO poisoning, and 200 people are admitted to hospital.

This may be just the tip of the iceberg. An inquiry led by the All-Party Parliamentary Carbon Monoxide Group (APPCOG), which resulted in the publication in 2015 of the report *Carbon Monoxide: from Awareness to Action,* identified that every year some 4,000 people attend emergency departments (ED) as a result of CO poisoning. Aside from the immense amount of human suffering that this represents, for both victims and their loved ones, it is estimated that the consequences of CO poisoning incidents cost the taxpayer at least £178m every year.

This report presents a series of essays by members of COMed, the dedicated healthcare sub-group of the APPCOG Stakeholder Forum (the Forum). COMed brings together healthcare professionals to discuss issues relating to CO and identify concrete measures by which these issues can be tackled. The Forum was established in 2012 in Parliament following the APPCOG's 2011 report, *Preventing Carbon Monoxide Poisoning*, which called for the establishment of a forum to coordinate campaigns, share knowledge, and strengthen links across the CO safety sector. Meeting on a quarterly basis in Parliament, the Forum brings together organisations from across academia, the energy industry and the third sector to collaborate on helping eradicate accidental CO poisoning.

CO poisoning can occur in a number of ordinary family settings - in the home, on camping trips, and when having a BBQ. Campaigns such as Gas Safety Week do a tremendous job of encouraging both householders and landlords to have their gas appliances serviced on an annual basis. But there is still a serious lack of awareness of CO risks associated with solid fuel appliances, particularly portable BBQs when used in camping and leisure contexts. Raising awareness and stimulating action to prevent CO poisoning requires collaboration between a large number of organisations.

Academics have a vital role to play in conducting research into the impact of CO on people's lives. Important work is already in hand at universities across the country: centres for CO research have been established at both Liverpool John Moores and Cranfield Universities, and research is also underway at Imperial College London and Newcastle University; investigations at John Moores are providing vital insights into the levels of CO found in homes across Merseyside and further afield. However, as this report makes clear, more research needs to be done to help healthcare professionals support their patients.

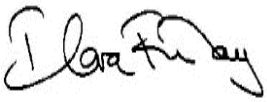
Healthcare professionals have an essential role in identifying, treating and preventing CO poisoning. From emergency services personnel to general practitioners, midwives to neurologists - all are at the front line of CO poisoning diagnosis. They are likely to be the first people to approach, or be approached by the victim of exposure, and are therefore best placed to intervene - prevent further poisoning, instigate appropriate treatment and facilitate recovery.

But clear definitions are needed of low dose exposure to CO, and of acute and chronic exposure, to ensure data on the effects are comparable and can be collated as biomarkers emerge. And healthcare professionals need to be given the right tools - they need to be sufficiently aware of CO risks, and the signs and symptoms that CO poisoning manifests, so they can diagnose accurately and ensure effective collaboration between relevant public services. The pressures faced by the National Health Service and other public sector bodies make it imperative that such measures are introduced in a cost-effective way.

The recommendations made in this report provide key starting points for the different types of action that need to be taken. The report compiles hard-hitting perspectives from across the healthcare disciplines, including contributions from specialists in the fields of toxicology, environmental health, midwifery, neurology, hyperbaric oxygen therapy, emergency medicine, paramedic practice and medical science. Representatives from all of these areas have a key role to play in efforts to identify, treat and reduce CO poisoning. The recommendations stemming from their contributions are therefore both timely and highly relevant.

As both a doctor and a parliamentarian, I would like to thank all those who have contributed their knowledge and expertise to this report and its recommendations. In order for positive change to happen, policymakers must be made aaware of this issue, and to be given clear guidance on the steps that need to be taken to minimise the dangers. By sharing their insights into this debilitating and deadly public health issue, the contributors to this report have provided a vital public service, allowing policymakers to gain a greater understanding of the wide-ranging effects of CO poisoning.

Lastly, I would like to extend special thanks to the chair of COMed, Isabella Myers, without whose dedication this report would not have happened. Through sharing the perspectives of healthcare professionals and providing concrete recommendations for action, this report will contribute in a meaningful and significant way to reducing the health impacts of CO poisoning incidents and preventing fatalities in the UK and beyond.



Professor the Baroness Finlay of Llandaff

Co-chair, All-Party Parliamentary Carbon Monoxide Group

3. EXECUTIVE SUMMARY

3.1. Carbon monoxide poisoning

Carbon monoxide (CO) poisoning is a serious public health issue. In England and Wales alone, every year some 4,000 attendances to emergency departments (EDs) are the result of accidental CO poisoning. Statistics show that CO kills more than 30 people a year and leads to around 200 hospital admissions, but these figures are likely to be a gross underestimate. Consequently, treating accidental CO poisoning may actually be costing much more than the estimated £178 million per annum.

Healthcare professionals have a vital role to play in preventing, diagnosing and treating patients exposed to CO. However, these professionals face a number of barriers to action: gaps in knowledge, limited awareness, and a lack of co-ordination within and between the healthcare sectors. These barriers need to be removed if we are to reduce significantly the number of accidental deaths and unnecessary injuries caused by CO poisoning, and to improve patient management and recovery.

This report has been prepared by members of COMed, the healthcare professionals' sub-group of the APPCOG Stakeholder Forum. It presents a number of hard-hitting essays that review current knowledge and practice on the diagnosis and management of CO poisoning in the healthcare system. It identifies gaps in knowledge and practice, and makes recommendations to close those gaps so that diagnosis, patient management and recovery can be improved.

The findings presented in this report led members of the sub-group to conclude that:

- A lack of awareness amongst healthcare professionals of CO poisoning as a cause of illness is very likely to be impacting adversely on public health outcomes.
- Much remains to be discovered and explained about the link between low level chronic CO exposure and long-term effects on an individual's health - for example, its impact on diseases of the cardiovascular and neurological system and whether CO is a casual factor of disease or involved in disease processes not previously associated with exposure to CO.
- Action is required throughout the healthcare profession, as well as by the Government, its Agencies, and Academia, to help protect the public from accidental CO poisoning.

3.1.1. What is CO?

CO is a colourless, odourless, tasteless, non-irritant poisonous gas, produced when any carbon-based fuel burns with an insufficient supply of oxygen. We know that CO binds to haemoglobin in the red blood cells, forming carboxyhaemoglobin (COHb). When this occurs, the ability of haemoglobin to take up oxygen is impaired and its ability to release the oxygen that it is already carrying is also impaired. This means that the body is deprived of oxygen, and tissues with a high demand for oxygen such as the brain are put at particular risk.

3.1.2. Where does CO come from?

There are many sources of CO in our environment. These include malfunctioning, inappropriately used, or poorly installed fossil or wood-fuelled cooking and heating appliances, such as stoves, boilers and heaters. Shisha pipes and other means of burning tobacco; cars, vans and lorries; fossil-fuelled generators; BBQs; candles and incense burners are also sources of CO.

3.1.3. What are the symptoms of CO poisoning?

Unfortunately there is no simple answer to this question. The symptoms of CO poisoning vary depending on whether the individual is suffering from acute (short term, under 24 hours) exposure to high levels of CO, or chronic (long term, over 24 hours) exposure to lower levels of CO. They also depend on the time that has elapsed since exposure. Symptoms become more severe quite rapidly as exposure levels increase. High levels of CO can cause coma and death within minutes. In cases of chronic exposure to lower levels of CO, symptoms

may become more marked until a steady state of exposure is reached, after which they are likely to remain constant until fresh, non-polluted air is breathed, as CO is removed from the body on breathing non-polluted air. The process of removal of CO can be accelerated by supplemental oxygen therapy.

Exposure to CO can cause a variety of non-specific symptoms, the most common of which are headache, nausea, vomiting, lethargy, flu-like symptoms, dizziness, and confusion. Poisoning can also cause shortness of breath, an abnormally rapid heart rate, fainting, seizures, paralysis, coma and death. Symptoms seen after acute high level exposure may also be seen in those who are exposed at a lower level. Delayed symptoms of poisoning - Delayed Neurological Sequelae (DNS) - can also occur weeks after a poisoning event when the patient has seemingly recovered.

In addition to the immediate effects of exposure to high concentrations of CO, non-lethal high-level exposure can have a significant and long-lasting impact on health including: epilepsy, emotional instability, accumulation of fluid within the brain (cerebral oedema), and Parkinsonism. However, much less is known about the risks of long-term repeated exposures to lower levels of CO. Exposure to repeated, short-term but higher levels of CO that does not produce symptoms may also have a detrimental effect on health.

3.1.4. Diagnosing CO poisoning

CO poisoning is difficult to diagnose. It first needs to be suspected - for reasons set out in this report this often does not happen – and it is clear that awareness amongst healthcare professionals needs to be raised. CO symptoms can be non-specific and mimic other conditions, and instruments and tests for measuring CO poisoning need to be consistently reliable and accurate. Taking a clinical history, exploring symptoms through careful, targeted questioning, making a thorough clinical examination, and requesting and interpreting the results of relevant laboratory investigations including COHb readings are the keys to a successful diagnosis. Healthcare professionals should also look for the physical signs of CO production within the homes of patients that they visit. Readings on personal alarms, if worn, would also provide clues. Patients known to be exposed to CO should be monitored, in some cases for many months.

3.2. Specialist essays: an overview

3.2.1. Environmental health

Environmental health practitioners (EHPs) working in the housing field can do much to help protect the public from CO poisoning. With access to properties in both the private and rented sectors, EHPs can look for the physical signs of CO production within the home alongside considering occupant health, wellbeing and safety. Importantly, EHPs also have enforcement capabilities. Anecdotal evidence suggests that there are a growing number of collaborative projects involving local authorities, fire brigades and the private sector that are raising awareness about CO safety, but more needs to be done.

In parallel there should be a specific, unambiguous legal requirement that a working battery operated CO alarm is provided in all new and rented properties, with an awareness-raising campaign on this mirroring those on gas certificates and tenant deposit protection.

3.2.2. Clinical toxicology and poisons information

All healthcare professionals can seek advice on treating those poisoned by CO via the National Poisons Information Service (NPIS), a service that provides advice on poisoning throughout the UK through TOXBASE® (the UK's clinical toxicology database, which provides evidence-based information on thousands of drugs and chemicals). If further advice is needed, this can be obtained by telephone 24-hours per day from a trained specialist in poisons information or, when necessary, a consultant clinical toxicologist. These specialists provide essential input to improving diagnosis and treatment of accidental poisonings.

To improve the tools available to all healthcare professionals more needs to be done to gather data on the effects of acute high level and chronic low level exposure to CO – especially for vulnerable groups – and combine such data with routinely-collected NPIS data. For example, instrumentation providing CO/%COHb concentrations needs to be consistently accurate and reliable, particularly for readings taken from patients

who might only have been exposed to lower levels of CO, to allow confidence in the use of such devices to assess the prevalence of low-level CO poisoning.

All current healthcare professionals should be adequately trained to manage CO poisoning in their particular setting.

Advances in these areas will improve patient care and help inform local health services of the issues involved, and provide the basis for monitoring and evaluating policies for tackling CO poisoning.

3.2.3. Paramedic practice

Ambulance crews assess, diagnose and treat patients, potentially in the place where they are being poisoned by CO, or on route to hospital. It is at this pre-hospital stage that early detection of CO is critically important for patient treatment as well as for the safety of the ambulance crew themselves. Currently, paramedics are not routinely equipped to identify CO as a risk factor for themselves or for their patients, despite occurrences of crew poisoning and inaccurate diagnosis in patients. With better CO detection devices and protocols that can be used by all paramedics, and the development of appropriate referral pathways, treatment for patients and crew safety will be improved.

3.2.4. Emergency medicine

The difficulties associated with diagnosing CO poisoning in an emergency department (ED) was made apparent in the published study by Clarke *et al* (2012), which described the assessment of patients for CO poisoning in four busy EDs. Difficulties predominately arise from the non-specific nature of the symptoms associated with CO poisoning: chest pain being treated as possible heart attack; vomiting as food poisoning; flu-like symptoms as flu. Diagnosis is easier in situations where a number of people have been poisoned as it raises suspicion in the clinician; unfortunately misdiagnosis often occurs in cases where only one or two people have been affected. The waiting time in EDs also makes it harder to diagnose CO poisoning. While patients wait to be seen in ED they are breathing air not polluted with CO, the CO washes out from the body and the COHb levels in the blood decrease. Thus, by the time the patient is seen by a physician, the evidence of having been exposed to CO might be unconvincing as COHb levels and symptoms will have diminished.

3.2.5. Hyperbaric oxygen therapy (HBOT)

Once in the care of medical professionals such as paramedics or hospital doctors, the main form of treatment for CO poisoning is by breathing pure oxygen or as near to pure oxygen as possible (the air we breathe contains only around 21% oxygen). This can sometimes be called normobaric oxygen therapy (NBOT).

In addition, some NHS hospitals in the UK have access to HBOT for CO poisoning. Treatment with HBOT is usually via a referral from a GP or ED physician. Patients may also be brought to the hyperbaric unit by ambulance directly from the place of poisoning.

The approach to the use of HBOT varies between different groups and organisations in the UK and Internationally. Professionals who refer patients for, or deliver HBOT believe that this treatment, when used early, can lessen the severity of persisting neurological sequelae in cases of more severe poisoning.

The use of HBOT can be recommended only on a case-by-case basis. The National Institute for Health and Care Excellence (NICE) and the NPIS do not recommend HBOT as a form of treatment for CO poisoning due to a lack of published evidence on its mechanism of action and difficulties with access to units providing HBOT. Some healthcare professionals do refer their patients for such treatment for acute CO poisoning under certain conditions (eg where the patient has been unconscious or is pregnant), however, further trials should be done as part of the current NHS England review into the use of HBOT.

3.2.6. In pregnancy

The UK Teratology Information Service (UKTIS), which provides information about the toxicity of drugs and chemicals in pregnancy, advises that following maternal exposure, carbon monoxide crosses the placenta and may reach similar concentrations in the fetus to that in the mother. Acute CO poisoning in pregnancy can lead to fetal and neonatal death, congenital malformations and neurological problems. Data also suggest that there may be an increased risk of such adverse outcomes after less severe maternal poisoning or following low level chronic exposure.

Given these dangers to the unborn child, it is right that in many maternity services in England CO screening is being done during the first appointment with the midwife. A breath analyser is used to record expired levels of CO in the woman's breath. If levels indicate a positive smoking status this is confirmed with the woman and an opt-out referral is made for stop-smoking support. Higher than expected levels should alert the midwife to the possibility of the woman having been exposed to CO from another source. When high levels of exposure to environmental CO are suspected, action is taken by the midwife based on local protocols and information disseminated during training.

Women should be made more aware of the risks of environmental CO poisoning, especially to the unborn child and to babies. This will be helped by more specific and better information on the risks and effects of CO exposure in these vulnerable individuals.

3.2.7. The effects of carbon monoxide exposure on the brain

The brain is particularly susceptible to CO poisoning. Severe neurological deficits can be seen in patients after acute CO poisoning, particularly if this included a period of unconsciousness. Subtle but significant neuropsychological problems can also follow chronic exposure to non-lethal levels of CO. Studies have described problems with brain functions such as memory and speech, and with neurobehavioural changes such as depression, anxiety and irritability.

Significant residual symptoms, particularly in the cognitive and neurobehavioural domains, may persist in the brain for 12 months or more - and may even be permanent. The longer-term difficulties following mild to moderate CO exposure are still not widely recognised. This can lead to people who have been affected feeling isolated and alone with their problems as even 'mild' residual disturbances in memory, executive function, mood, personality and social behaviour can make it hard for the individual to reintegrate within the family and return to employment.

Such changes may not be easy to identify and the causal link with CO poisoning may not be obvious. For example, subtle changes on MRI following CO exposure may be overlooked on routine scans, and many people who do have normal imaging can still have significant neuropsychological impairment. More needs to be done to gain experience and expertise and to support and treat individuals so affected.

3.2.8. Carbon monoxide poisoning – gaps in scientific knowledge

One of the challenges facing healthcare professionals in both diagnosing and treating cases of CO exposure is the relative dearth of fundamental, pre-clinical research to support an evidence-based medicine approach. Neurological and neuropsychological impairments are well described in patients who have been exposed to CO, but we are far from establishing specific mechanistic connections between CO exposure and the resulting cognitive and emotional symptoms.

The knowledge gaps exposed in this report need to be addressed by pre-clinical studies using animal models to underpin more solidly current clinical practice, in order to: study the effects of CO on the brain under carefully controlled and reproducible conditions, evaluate rigorously potential new treatment strategies, and allow mechanistic studies that may identify novel biomarkers.

Some key questions to be answered are:

- Is there any low-level CO exposure limit that is 'safe'?
- Do repeated low-level exposures to CO result in neurological deficits?
- Can reliable 'biomarkers' for both high and low level CO exposure be identified?
- Are particular groups (*eg* the elderly or pregnant women) more susceptible to the effects of CO?
- Can a mechanistic evidence base be established for current treatment?
- Can novel therapeutic interventions for CO poisoning be developed?

3.2.9. Case studies

The case studies included throughout this report highlight situations of multiple as well as single person poisoning, some occurring in situations where poisoning had not previously been experienced. Emergency response teams are aware that sometimes the source of CO can be found in neighbouring properties, since it can travel through and between properties, particularly in multi-occupant buildings. When GPs have patients

who visit repeatedly over a number of weeks with relevant symptoms they should always suspect CO poisoning as a possible cause. The energy and fuel sectors need to help to raise awareness by setting out the types of situation and circumstances in which exposure can take place. It is imperative that engineers from the fuel sector help to reduce delays in establishing the source of CO.

4. RECOMMENDATIONS

Each essay in Section 7 includes specific recommendations and these are listed below in the order in which they appear in the essays (recommendations 1-19). Other recommendations have been made following Members' consideration of the individual healthcare essays; these are also set out in this section (recommendations 20-26), Taken together they form a package of measures that will assist the healthcare and other sectors to deal with this invisible threat to physical and mental health through better diagnosis and treatment of CO poisoning.

Recommendation 1

The *Residential Inspection Aid on Carbon Monoxide*, produced by Public Heath England and the Chartered Institute of Environmental Health, should be reviewed in line with the current evidence base and be externally validated. The Aid should be made accessible to environmental health professionals and all those involved in carrying out housing inspections and assessing housing standards.

Recommendation 2

All landlords in England and Wales should be legally required, as is the case in Scotland, to install CO alarms in all private and public rented sector properties that contain a fuel burning appliance of any kind. Failure by the landlord to provide and maintain the alarm should result in enforcement action.

Recommendation 3

Researchers working in biomedical and bioengineering university departments should be encouraged to conduct research on the strengths and weaknesses of current methods used to measure CO exposure in patients, including venous %COHb, with a view to refining these methods and also progressing the identification of new biomarkers of exposure.

Recommendation 4

A review should be conducted of existing methods of data collection regarding patient related exposures, to gain information on the effectiveness of care and trends in poisonings, inform local services of issues, and provide the basis for monitoring and evaluating policies for tackling CO poisoning.

Recommendation 5

E-learning opportunities should be provided to all current healthcare professionals via existing on-line resources *eg* www.TOXlearning.co.uk. E-learning modules should be created to inform on the agreed use of medical devices and protocols in diagnosing and managing the CO poisoned patient, with GP, paramedic and emergency department specific modules.

Recommendation 6

Paramedics and other emergency service personnel should be equipped with accurate and reliable personal CO monitors to protect themselves, and non-invasive devices to aid in patient diagnosis.

Recommendation 7

NHS ambulance services, Voluntary Aid Societies (VAS) and private ambulance companies should provide ambulance staff and other emergency service personnel with sufficient training to enable rapid and accurate diagnosis of CO poisoning. This should include the provision of software within the ambulance control call-taking system to recognise the indicators of CO poisoning.

Recommendation 8

Mandatory reporting of CO incidences should be introduced for healthcare professionals. Reported data should then be collated by Public Health England and equivalent bodies in the devolved countries of the UK.

Recommendation 9

Emergency departments should adopt validated, rapid triage systems (*eg* Manchester Triage System) and combine this with the use of the COMA questions and early COHb measurement, together with targeted, rapid screening of specific groups of patients presenting at EDs, *eg* patients with dizziness, non-traumatic headaches, flu-like symptoms, seizures and chest pain.

Recommendation 10

Health Education England and the Academy of Medical Royal Colleges should support widely available and standardised training on CO poisoning throughout undergraduate and postgraduate medical training to raise awareness and improve diagnosis and treatment of CO poisoning.

Recommendation 11

To accelerate diagnosis of CO poisoning and the initiation of treatment, the Royal College of Emergency Medicine, the College of Paramedics and the joint Royal Colleges Ambulance Liaison Committee should lead the development of a COHb screening protocol and, with industry, a rapid standardised scene assessment procedure to determine indoor air CO levels, for use by emergency service personnel and by research scientists.

Recommendation 12

A prevalence study should be conducted to estimate the true cost of CO poisoning to the National Health Service.

Recommendation 13

Research needs to be funded to produce rigorous evidence that confirms or refutes the role that HBOT has in the treatment of CO poisoning, in particular with regard to its effect on reducing the risk of developing long term neurocognitive conditions.

Recommendation 14

NICE and NPIS should consider the evidence generated by the research proposed in Recommendation 13, to establish whether HBOT should be included as a recommended treatment option for CO poisoning in terms of effectiveness, cost and availability across the NHS.

Recommendation 15

A working group should be established to enable key organisations to develop a robust evidence-based pathway for the identification and prevention of exposure to environmental CO. These organisations would include: PHE, RCM, RCOG, Ofgem, HEE and NHSE along with academic colleagues and charities such as GST, SANDS, Tommy's and the Lullaby Trust.

Recommendation 16

Appropriate funding bodies should fund research in order to: provide a better understanding of the scale of environmental CO poisoning in pregnancy; establish the effects of repeated low dose exposure to CO on the developing fetus; gain a better understanding of the barriers and facilitators to the identification of CO poisoning in pregnant women; understand how better to protect women from CO poisoning by the actions of health professionals and other agencies; and, provide better information to individuals to help them protect themselves.

Recommendation 17

The Royal College of GPs, the Royal College of Psychiatrists and the Royal College of Physicians should collaborate to raise awareness amongst GPs, neurologists and psychiatrists on the long-term cognitive and neurobehavioral effects of mild-moderate CO exposure. GPs should consider CO poisoning as a potential cause when treating patients presenting with chronic neuropsychiatric complaints.

Recommendation 18

NHS England should develop specialist referral clinics to support and treat people with persisting mild-moderate cognitive and neurobehavioral problems following confirmed CO exposure. This will improve both treatment and the understanding of the profiles of chronic CO exposure in individuals, and improve the availability of mental health services that are required to treat patients exposed to CO.

Recommendation 19

Appropriate medical and healthcare funding bodies such as the Medical Research Council and Wellcome Trust - among others - should fund appropriate research on CO toxicity to explore the effects of low-level CO exposure and potential treatment options. Pre-clinical animal models allowing standardised CO exposure, rigorous comparisons between treatments, and validation of novel biomarkers, would provide an evidence base to underpin translation of effective diagnostic and treatment strategies to the clinic.

Recommendation 20

Public Health England should develop a clear protocol for the diagnosis, treatment and follow-up of patients after CO exposure, to be published online and used across the healthcare sector. The Home Office should promote the use of the protocol alongside existing diagnostic algorithms across the blue-light services, to enable faster and more effective identification of CO poisoning incidents.

Recommendation 21

NPIS should coordinate the creation of an anonymised database of CO poisoning incidents, which could be shared appropriately with relevant stakeholders to enable faster identification of emerging causes of CO poisoning.

Recommendation 22

The Health and Safety Executive should require establishments that prepare hot food to provide CO alarms to domestic and workplace premises above or immediately adjacent to them.

Recommendation 23

NICE with support from Public Health England should develop guidance specifically on CO exposure in the indoor environment, taking input from healthcare professionals, charities and built environment professionals.

Recommendation 24

A literature review is required to assess the association of CO exposure with specific health conditions, to inform the scientific, healthcare and industry sectors.

Recommendation 25

Health Education England, together with the Academy of Medical Royal Colleges and Public Health England, should deliver high quality education and training programmes on CO poisoning and its treatment to all health professionals at undergraduate and postgraduate level. This will help to ensure that the need for a joined-up approach in understanding patient requirements, emergency response and occupational risk is recognised.

Recommendation 26

The Healthcare and Academic community should together develop standard definitions for the different levels and durations of CO exposure; and achieve consensus on both the treatment protocols and the description of neurological sequelae, in order to improve the management of CO poisoning and help the research community produce directly comparable data.

5. BACKGROUND TO SPECIALIST ESSAYS

5.1. Status, scope and methodology

In its 2011 inquiry and report, *Preventing Carbon Monoxide Poisoning*, the All-Party Parliamentary Carbon Monoxide Group[1] (previously called the All-Party Parliamentary Gas Safety Group), explored the role of healthcare professionals in preventing, diagnosing and treating carbon monoxide (CO) poisoning. It made a number of recommendations, including calls for improved training and equipment to detect and respond to CO poisoning, and to fill evidence gaps. Linked to the APPCOG is the APPCOG Stakeholder Forum (the Forum), a coalition of industry and healthcare professionals, researchers, civil servants and campaigners, which works to identify ways to prevent CO poisoning in the UK. A Healthcare Professionals Group (COMed) sits within the Forum, designed to drive forward CO-related activities in the relevant professions.

The Forum commissioned this report as part of its work to promote CO-related activities amongst relevant professionals. The report is targeted at practitioners, medical colleges, healthcare policy-makers and parliamentarians, as well as at relevant government departments, research funding bodies and charities. The report sets out the current state of play on CO poisoning diagnosis and response in each of the individual specialties, and suggests how current knowledge and practice may be improved.

A key concern of Forum members was that healthcare professionals were not only missing cases of CO poisoning, but misdiagnosing CO poisoning and therefore not appropriately managing cases. The Forum wanted to establish why this was so and asked:

- What are the barriers to making a correct diagnosis?
- Are these barriers intrinsic to the non-specific features of CO poisoning?
- Are they associated with the assessment environment (eg emergency departments (EDs), homes, surgeries) in which a diagnosis is made?
- Is there a lack of access to appropriate medical equipment and diagnostic tests that would assist in making or confirming a diagnosis?
- Is there an institutional lack of awareness of CO poisoning amongst healthcare professionals because it is considered rare, or because of a lack of training?

The report is a compilation of essays that seek to answer these questions. Each essay can be read as a stand-alone document, covering a healthcare specialism. Authors have provided reflections based on their own practical experiences and relevant literature. As such, unless stated otherwise, the sections do not represent a particular organisational view.

5.2. Carbon monoxide poisoning: a serious problem

CO is an odourless, colourless, tasteless and non-irritant gas which is produced when carbon-based fuels such as coal, gas, coke and wood burn without enough air. This can happen when appliances such as heaters, boilers and cookers are not used in accordance with manufacturer's instructions, malfunction, are incorrectly installed, or when flues or chimneys become blocked. CO is an inevitable component of combustion exhaust gas when carbon-based fuels burn, even when combustion is efficient. Hence the need for properly working flues and chimneys. With less efficient combustion, CO levels in exhaust gas rise. The combination of inefficient combustion and inefficient venting of exhaust is particularly dangerous.

Accidental poisoning by CO gas is a serious, but preventable, public health problem. According to official estimates, each year CO poisoning accounts for some 4,000 recognised visits to EDs in England, as well as over

[1] www.policyconnect.org.uk/appcog

30 deaths and 200 hospitalisations in the UK[1]. However, it is widely acknowledged that these figures probably underestimate the scale of the problem, particularly for chronic, low level poisoning due to the non-specific symptoms of poisoning that make diagnosis difficult[2]. A key challenge relates to difficulties in diagnosis; the symptoms of sub-lethal poisoning often mimic other, more common illnesses such as flu and food poisoning. CO exposure can also precipitate exacerbations of other chronic diseases of the cardiovascular or neurological system[3,4]. The most common symptom of CO poisoning is headache – a very common symptom of other ills. Other common symptoms include nausea, vomiting, vertigo, syncope, breathlessness, fits and loss of consciousness[5].

Exposure to high concentrations of CO leads to collapse and death within minutes[6]. Sub-lethal levels of CO poisoning can lead to chronic health problems, particularly lasting neurological damage that include difficulties in concentrating and severe mood changes. Older people, children, and those with breathing problems or cardiovascular disease are at increased risk. Pregnant women and their unborn children are also at particular risk because fetal blood has a high affinity for CO. COHb also persists in fetal blood long after maternal exposure has ceased. Exposure of CO to the developing fetus has been linked to poor birth outcomes[7].

5.2.1. Carbon monoxide poisoning: effects on health

By impeding both the binding of oxygen to haemoglobin and the release of oxygen molecules that do find binding sites, CO deprives tissues of oxygen, particularly those with a high metabolic rate. This induces a state of hypoxia, despite a normal concentration of oxygen being inhaled. This is why it is important that neither the partial pressure of oxygen in the blood, nor the saturation of haemoglobin directly calculated from the partial pressure of oxygen should be used as an aid to diagnosis. The state of hypoxia causes many cellular functions to fail; it can result in brain cell death and, if of great enough severity, death of the patient. In addition, CO binds to molecules in the mitochondria and reduces the ability of the cell to use any available oxygen. The cells die due to the hypoxic state reducing the cells' ability to produce adenosine triphosphate (ATP), which is required for the production of energy within cells. CO binds to haemoglobin in exactly the same way as O_2, although haemoglobin has a greater affinity for CO than O_2; therefore, as more CO becomes available, more CO than O_2 will bind to haemoglobin and reduced amounts of O_2 will be released by the haemoglobin. It is this high affinity that makes even low concentrations of CO dangerous, particularly for the developing fetus: fetal blood has even greater affinity for CO than that of an adult[8].

CO also affects the binding of O_2 to other molecules such as myoglobin (a haem protein found in muscle cells such as cardiac and skeletal muscle). Currently, research is being undertaken to establish the effect of CO binding to other haem proteins.

Direct cellular damage by non-hypoxic mechanisms is also described in the literature. Such detail is beyond the scope of this report, but further information can be found in the peer-reviewed literature.

5.2.2. Carbon monoxide poisoning: treatment

Treatment requires patients to be removed from the CO contaminated environment to one free from CO where the patient should breathe normally. If indicated, supplemental oxygen (*eg* 100%) should be supplied either via a tightly fitting mask, through an endotracheal tube, or in a HBOT chamber. COHb has a half-life of around 5 hours in normal air, which reduces to 60-90 minutes if 100% oxygen is given under normobaric conditions. Oxygen therapy aims to displace CO from haemoglobin and restore its normal oxygen carrying capacity.

[1] http://www.hse.gov.uk/gas/domestic/cross-government-group.htm
[2] S. Clarke, C. Keshishian, V. Murray 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, vol. 2, no. 6, Article ID e000877, 2012
[3] J. A Raub and V.A Benignus. Carbon monoxide and the nervous system, Neurosci, Biobehav.Rev., 2002, 26, 925-940
[4] F.L Lowe-Ponsford and J.A Henry, Clinical aspect of carbon monoxide poisoning, Adverse Drug React. Acute Poisoning Rev.1989, 8, 217-240
[5] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/260211/Carbon_Monoxide_Letter_2013_FinalforPub.pdf
[6] http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf
[7] http://www.medicinesinpregnancy.org/bumps/monographs/EXPOSURE-TO-CARBON-MONOXIDE-IN-PREGNANCY/
[8] Maynard RL and Myers J (2015) Carbon monoxide, in Purser D, Maynard RL & Wakefield J [Eds] Toxicology, Survival and Health Hazards of Combustion Products. Royal Society of Chemistry.

5.2.3. Carbon monoxide poisoning: standards and guidelines

Air quality standards for workplace exposures have been established as follows:

Figure 1: Workplace exposure levels

	8 hour time weighted average	15 minute time weighted average
CO	30ppm	200ppm
	35 mg/m^3	232 mg/m^3

Source: [Health & Safety Executive, 2011][1]

The World Health Organization in 2010 produced the following indoor air quality guidelines for acute exposure to CO, but also produced a 24-hour averaging time to provide a guideline for chronic exposure to CO. These guidelines are provided for the protection of health and are guidelines, not law. Their influence is limited due to the difficulty of enforcement in the domestic environment. The WHO guidelines are as follows:

Figure 2: WHO guidelines for indoor exposure – CO

Averaging time	Concentration (mg/m^3)
15 minutes	100
1 hour	35
8 hours	10
24 hours	7

Source: [WHO 2010][2]

Prior to this, in 2004, the UK's Committee on the Medical Effects of Air Pollutants (COMEAP) produced their report *Indoor Air Quality Guidance* that provided a health-based guideline for CO exposure indoors. This was in line with the WHO outdoor air quality guideline and was the first such attempt to produce a health-based indoor air quality guideline for exposure to CO[3].

5.2.4. Carbon monoxide poisoning: specialisms and ways forward

The report contains submissions from only selected sectors of the healthcare profession. This is due entirely to the current membership of the sub-group: no emphasis has been placed on these specialisms through any prior decision to downplay other healthcare specialties. Having established the current situation within the specialties represented, it is clear that the evidence points toward a need to work in collaboration with a wider group of healthcare professionals to facilitate an improvement in prevention, diagnosis and treatment of CO poisoning. Further investigation is required to identify and drive forward the work on CO exposure in relation to specific disease areas, and similar work is required on the effects of CO on tissues and organs. Establishing whether there are associations between CO and specific disease areas, the strength of such associations, and what the potential mechanisms might be, will allow for a better understanding of the possible impacts of CO on public health in terms of death and disability. It will also inform stakeholders with an interest in the prevention and treatment of and recovery from CO poisoning. Naturally, such work and analysis of data will also inform government and assist with the development of policies associated with the protection of health and prevention of CO poisoning.

[1] http://www.hse.gov.uk/pubns/books/eh40.htm
[2] http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf
[3] http://webarchive.nationalarchives.gov.uk/20140505104658/http://www.comeap.org.uk/documents/reports/39-page/linking/67-indoor-air-pollutants

6. SPECIALISTS' ESSAYS

6.1. Carbon monoxide poisoning: environmental health

Bob Mayho, former Principal Policy Officer, (housing policy), Chartered Institute of Environmental Health (until January 2017)

Case Study

A woman in a flat has a carbon monoxide (CO) alarm installed, which starts to sound repeatedly in the early hours of the morning. A gas engineer is called, but finds no problem in the house. Further investigation of the restaurant below the flat reveals CO in the kitchen and seating area of the restaurant. The gas supply to the restaurant is shut off. However, over the next 6 months, the resident's alarm continues to sound in the early hours of the morning. Further investigation of the restaurant reveals the source of CO as the charcoal burning tandoor oven which is left smouldering at night with the extractor fan turned off. This issue is only resolved when the resident becomes so ill she calls the emergency services, resulting in a response that also involves the local authority and Public Health England.

Carbon monoxide (CO) poisoning is not uncommon. Studies have shown, for example, that between 6 and 20 per cent of homes in London have CO levels above World Health Organization recommended upper limits[1]. Figures from the gas industry indicate that 3 out of 5 boilers are unsafe and 1 out of 5 is dangerous enough to require immediate disconnection[2].

Environmental health practitioners (EHPs) working within the housing field use the housing health and safety rating system (HHSRS)[3], a risk-based evaluation tool to identify and protect against potential risks and hazards to health and safety from any deficiencies identified in dwellings. It was introduced under the Housing Act 2004 and applies to residential properties in England and Wales. The system is supported by statutory operational and enforcement guidance which offers EHPs advice on identifying and dealing with hazards.

CO and fuel combustion products are listed as one of the 29 hazards under the rating system. This category includes hazards resulting from the presence of excess levels in the atmosphere within the dwelling of CO, nitrogen dioxide, sulphur dioxide and smoke, all products associated with the combustion, or incomplete combustion, of gas, oil, and solid fuels for heating and cooking.

6.1.1. Current knowledge and practice

The HHSRS is founded on the logical evaluation of both the likelihood of an occurrence that could cause harm, and the probable severity of the outcomes of such an occurrence. It relies on informed professional judgements on both of these to provide a simple means of representing the severity of any dangers present in a dwelling. The HHSRS is evidence-based. It is supported by extensive reviews of the literature and by detailed analyses of statistical data on the impact of housing conditions on health.

While the HHSRS can be used to judge the effectiveness of remedial action, it cannot determine or suggest that action – professional judgement is required based on the particular circumstances, including the design and construction of the dwelling.

The assessment using the HHSRS is made based on the condition of the whole dwelling. This means that, before such an assessment can be made, a thorough inspection of the dwelling must be carried out to collect evidence of its condition. Inspectors require an understanding and appreciation of the potential effects that could result from conditions and deficiencies identified during the inspection.

The HHSRS concentrates on threats to health and safety. It is generally not concerned with matters of quality, comfort and convenience. However, in some cases, such matters could also have an impact on a person's physical or mental health or safety and so can be considered. As the rating system is also about the assessment of hazards (the potential effect of conditions), the form of construction and the type and age of the dwelling do not directly affect an assessment. However, these matters will be relevant to determining the cause of any problem and so indicate the nature of any remedial action.

[1] Croxford 2005 [1], 2005 [2], 2007. Available online at: http://discovery.ucl.ac.uk/5017/1/5017.pdf
[2] http://www.policyconnect.org.uk/appcog/sites/site_appcog/files/event/590/fieldeventdownloads/summaryappcogwsbfsmartmeterpaneldisucssion.pdf
[3] Housing Act 2004, available online at: http://www.legislation.gov.uk/ukpga/2004/34/contents

The operational and enforcement guidance available to practitioners[1] is based on original research and evidence from the time the HHSRS was first devised and brought forward into law. The Chartered Institute for Environmental Health (CIEH) has been pressing government to instigate a review of the operational guidance for some time. The Regulatory Impact Assessment accompanying the Housing Act 2004 proposed a formal monitoring process of the new enforcement regime. It suggested an evaluation commissioned within three years of implementation, in line with that intended for the proposed monitoring of the licensing regime for houses of multiple occupation (HMO). Importantly, this would enable an assessment of the impact and effectiveness of the enforcement regime, particularly through the use of the HHSRS as an enforcement tool. Neither has happened.

In 2014 the government issued a discussion paper[2] reviewing housing conditions in the private rented sector. In responding, the CIEH[3] reiterated our view that there should be a specific, unambiguous requirement that a working battery CO detector is provided in all rented property, fitted in the correct location, at the commencement of a tenancy. The replacement of detectors should be taken into consideration in line with their working life. There should be an awareness-raising campaign on this, as there has been with gas certificates, energy performance certificates (EPCs) and deposit protection.

6.1.2. Ways forward

At present, despite CO being one of the most common causes of accidental poisoning in the UK, landlords are only required to install CO alarms in properties that contain solid fuel burning appliances, such as open fireplaces and wood-burners.

The CIEH is concerned that the austerity measures of recent years and subsequent cuts to housing support might exacerbate the fact that CO poisoning tends to affect the most vulnerable members of the community, such as elderly people living in private rented accommodation. CIEH members working in housing are responsible for regulating the private rented housing sector (enforcing housing legislation) and our concern is that environmental health capacity is being reduced resulting in fewer resources to tackle rogue landlords, many of whom operate under the radar.

We have proposed legislation that would make compulsory the installation of CO monitors in all new and any tenanted (both public and private) dwellings that have any solid, oil or gas burning appliances for space or water heating or for cooking, and for any dwelling above or immediately adjacent to restaurants, cafes, bars or other cooked food outlets.

In order to raise awareness among EHPs of the dangers of CO and to help reduce CO poisoning incidents, the CIEH and Public Health England (PHE) have produced a housing inspection aid. The one page checklist outlines key indicators of the possible presence of CO and the symptoms in occupants that should be looked for.

The guidance advises environmental health practitioners to recommend to occupants that they fit their home with an audible CO alarm compliant with British Standard EN50291. This is an additional measure and the installation of an alarm should not replace regular gas safety checks and servicing of appliances by an appropriately registered engineer. The *CIEH/PHE Residential Inspection Aid: Carbon Monoxide* can be downloaded from the CIEH website[4].

Anecdotal evidence suggests that there are a growing number of collaborative projects involving local authorities, fire brigades and the private sector which seek to raise awareness about CO safety. However, currently, there is no co-ordination of these efforts.

6.1.3. Conclusions

Environmental health practitioners working in housing, particularly in the private rented sector, are responsible for ensuring that rented property is safe and properly maintained. To do this they use the HHSRS to identify and protect against potential risks and hazards to health and safety from any deficiencies identified

[1] HHSRS Operational Guidance (2004), available online at: https://www.gov.uk/government/publications/hhsrs-operating-guidance-housing-act-2004-guidance-about-inspections-and-assessment-of-hazards-given-under-section-9

[2] DCLG Review of Property Conditions in the Private Rented Sector – A Discussion Paper (January 2014), available online at: https://www.gov.uk/government/publications/review-of-property-conditions-in-the-private-rented-sector

[3] CIEH Response to the DCLG Review of Property Conditions in the Private Rented Sector, available online at: http://www.cieh.org/WorkArea/showcontent.aspx?id=52218

[4] http://www.cieh.org/advresult.aspx?SearchBox=carbon%20monoxide

in dwellings. CO is a listed hazard under the system and officers using the system have powers to require landlords to repair or replace equipment to remedy faults and remove the hazard.

In response to a recent government discussion paper on conditions in the private rented sector, which included questions about whether CO monitors and alarms should be required by law to be installed in rented property, the CIEH reiterated its established position that there should be a specific, unambiguous requirement that a working battery operated CO detector is provided in all new and rented properties, fitted at the commencement of a tenancy in the correct location. There should be an awareness-raising campaign on this, as there has been with gas certificates, EPCs and deposit protection.

The CIEH has worked alongside PHE to produce a housing inspection aid, for environmental health practitioners and others responsible for housing inspections, to raise awareness of the dangers of CO and to help reduce CO poisoning incidents.

Recommendation 1

The *Residential Inspection Aid on Carbon Monoxide*, produced by Public Heath England and the Chartered Institute of Environmental Health, should be reviewed in line with the current evidence base and be externally validated. The Aid should be made accessible to environmental health professionals and all those involved in carrying out housing inspections and assessing housing standards.

Recommendation 2

All landlords in England and Wales should be legally required, as is the case in Scotland, to install CO alarms in all private and public rented sector properties that contain a fuel burning appliance of any kind. Failure by the landlord to provide and maintain the alarm should result in enforcement action.

6.2. Carbon monoxide poisoning: clinical toxicology and poisons information

Dr Aravindan Veiraiah, Consultant Physician, Royal Infirmary of Edinburgh
Dr Gill Jackson, Information Services Manager, National Poisons Information Service

Case Study

The National Poisons Information Service (NPIS) was called about a case concerning a couple who had been brought to hospital with carbon monoxide (CO) poisoning while on holiday. They had used a range style cooker and a coal fire without adequate ventilation. The man had woken up in the middle of the night with a headache, nausea and was unsteady on his feet. On investigation, the man had a carboxyhaemoglobin (COHb) concentration of 15.3%, while the woman had a concentration of 7%. The man still had a headache at the time of the call, but no neurological signs of poisoning. The woman was asymptomatic. Following advice, the patients continued to receive 100% oxygen via a tightly-fitted mask until COHb was less than 5%. Both were asymptomatic when they were discharged.

NPIS via TOXBASE® is able to provide consistent advice on the management of CO poisoning to all healthcare professionals throughout the UK and has the potential to monitor incidents/cases very efficiently.

Clinical toxicologists manage poisoned patients. Some contribute sessions to the National Poisons Information Service (NPIS), a service that provides advice to health professionals on poisoning throughout the UK through TOXBASE® (the UK's clinical toxicology database) and the NPIS telephone enquiry service, including advice on appropriate referral to public health. Clinical toxicologists also teach students and NHS staff about the management of poisoning from a range of toxins, including carbon monoxide (CO).

6.2.1. Current knowledge and practice

Clinical toxicologists become involved in cases of CO poisoning when contacted about a case by their emergency department, or via a TOXBASE® or telephone enquiry. The majority of cases are easy to treat based upon advice available in TOXBASE®, as well as in toxicology outpatients units.

The NPIS is currently collecting contact and anonymised case details from healthcare professionals who access CO advice via TOXBASE®, so that all TOXBASE® accesses and telephone enquiries to the NPIS can be followed up.

Between 1 July 2015 and 31 June 2016 there were 3270 TOXBASE® enquiry sessions and 273 NPIS telephone enquiries involving CO. Follow up data became available for 832 patient exposures, which includes data on four unintentional deaths. The majority of TOXBASE® sessions (68%) came from hospitals, the majority of telephone enquiries (37%) were from NHS111/24/Direct.

There are three key challenges that need to be addressed to improve diagnosis and treatment of accidental CO poisoning in the UK:

- Understanding the significance of mildly elevated breath CO measurements in patients with no obvious exposure to CO. Clinicians can be called about a patient with an inexplicable COHb concentration of 12%, which may reflect speed of exhalation or a false positive exposure due to raised expired-air H2 concentrations in lactose intolerant patients. However, a false positive cannot be assumed without further investigation.
- Identifying cases and determining outcomes.
- Avoiding confusion around differing advice on treatment. The Chief Medical Officer in her 2015 letter[1] to healthcare professionals recommends consideration of hyperbaric oxygen therapy (HBOT) on a case by case basis: the NPIS does not recommend this therapy.

6.2.2. Ways forward

The reliability and accuracy of non-invasive CO measurements, especially in patients with mildly elevated levels of CO/%COHb, need to be determined before judgments on the prevalence of chronic exposure to low levels of CO are made based upon the use of these devices alone.

[1] https://www.gov.uk/government/publications/carbon-monoxide-poisoning

The data on incidence and outcomes of CO poisoning in the UK should be determined. It is acknowledged that data sets are currently incomplete, which prevents a clear and reliable understanding of poisoning prevalence. NPIS data should usefully contribute to a better understanding of the prevalence of CO in the population.

6.2.3. Conclusions

The NPIS provides medical advice on suspected cases of CO poisoning in the UK and is currently alerted by the use of their online database or by calls to their telephone enquiry service. The significance of mildly elevated breath CO measurements and %COHb blood measurements needs to be determined before the true prevalence of chronic CO poisoning in the UK can be calculated.

Recommendation 3

Researchers working in biomedical and bioengineering university departments should be encouraged to conduct research on the strengths and weaknesses of current methods used to measure CO exposure in patients, including venous %COHb, with a view to refining these methods and also progressing the identification of new biomarkers of exposure.

Recommendation 4

A review should be conducted of existing methods of data collection regarding patient related exposures, to gain information on the effectiveness of care and trends in poisonings, inform local services of issues, and provide the basis for monitoring and evaluating policies for tackling CO poisoning.

Recommendation 5

E-learning opportunities should be provided to all current healthcare professionals via existing on-line resources *eg* www.TOXlearning.co.uk. E-learning modules should be created to inform on the agreed use of medical devices and protocols in diagnosing and managing the CO poisoned patient, with GP, paramedic and emergency department specific modules.

6.3. Carbon monoxide poisoning: paramedic practice

Andrew Humber, Hazardous Area Response Team (HART), London Ambulance Service

Patient Safety – Case Study 1

An ambulance was called to a 24 year old male who had fainted at work. The male was in an enclosed area using petrol powered concrete cutting equipment; other powered tools similar to this were also being used. The patient had been unconscious and was complaining of dizziness on the crew's arrival. All observations were normal except for an otherwise unexplained tachycardia. The ambulance crew took the patient to hospital and diagnosed a fainting episode. Approximately two hours later the ambulance service received a call back to the industrial site as several members of staff were feeling unwell with nausea, vomiting and dizziness although none had lost consciousness. Eleven further patients were identified with SpCO of between 13 and 26%; all were transported to hospital and treated for the effects of carbon monoxide (CO) poisoning. The first crew on the scene noted that it was a hot environment and was aware of the power tools being used but did not think of the possible CO implication. If CO had been detected in the first patient or the crew alerted through the use of a personal CO alarm, then the other persons involved would not have been further exposed.

Crew Safety – Case Study 1

In December 2015, paramedics from Preston in Lancashire were administering CPR to an elderly man who had collapsed in his home, they then themselves began to feel unwell and dizzy. The elderly man unfortunately lost his life; his son and four of the paramedics had to be treated in hospital for CO poisoning[1].

Crew Safety – Case Study 2

April 2016, two paramedics from Newcastle, County Down, Northern Ireland were treated in hospital for CO poisoning after attending a patient who had collapsed at a domestic address[2].

Ambulance personnel assess, diagnose, treat and transport patients in the pre-hospital setting. It is at this stage that detection of carbon monoxide (CO) is critically important both for patient treatment and ambulance crew safety[3].

6.3.1. Current practice

Ambulance service crews are called to situations where CO might be suspected. There are also situations attended by ambulance crews where CO is not recognised by the call operator; this can result in paramedics being exposed to CO. Paramedics enter the premises, where patients are assessed and treated, prior to moving the patient outside or to an ambulance for transport to hospital. Currently, paramedics are not routinely equipped to identify CO as a risk factor for themselves or their patients.

6.3.2. Ways forward

There is a need to demonstrate the benefit of pre-hospital monitoring for CO in terms of accurate diagnosis, initiation of early appropriate treatment and facilitating the most suitable referral pathway for patients.

There is a need for paramedics to be provided with indoor air monitoring equipment and patient diagnostic equipment and for appropriate protocols and care pathways to be developed. In this way, crews would be alerted to elevated CO levels in the environment where assessment takes place and be able to assess patients, pre-hospital, for CO poisoning and to facilitate a co-ordinated approach once the patient is handed over to emergency department clinicians.

6.3.3. Conclusions

Previous incidents demonstrate that on many occasions ambulance personnel have been inadvertently exposed to elevated CO concentrations, whilst performing their clinical assessment and treatment of patients.

[1] http://www.itv.com/news/granada/2015-12-17/paramedics-were-poisoned-by-carbon-monoxide/
[2] http://news.sky.com/story/paramedics-poisoned-by-carbon-monoxide-10263484
[3] Humber, A. (2009) A feasibility study into pre-hospital carbon monoxide monitoring for patients. (Report available via secretariat)

In such cases, attending ambulance personnel have neither the equipment nor the protocols to diagnose CO poisoning as the presenting medical condition.

By using a pulse CO-oximeter / exhaled CO breath analysers for routine patient assessment, clinicians have been alerted to raised levels of %COHb / exhaled CO, enabling appropriate early treatment and rapid extraction of patient and ambulance personnel from a hazardous environment. A lack of knowledge amongst the emergency services of the signs and symptoms that suggest CO poisoning have placed blue light responders at risk of CO poisoning.

Following a review of previous incidents, it is clear that many CO poisoning cases had not been recognised or reported and suspicion of CO exposure had not been shared between the emergency services. Data on CO poisoning is not collated nationally from the emergency service and therefore the true prevalence of CO poisoning events remains unknown.

Recommendation 6

Paramedics and other emergency service personnel should be equipped with accurate and reliable personal CO monitors to protect themselves, and non-invasive devices to aid in patient diagnosis.

Recommendation 7

NHS ambulance services, Voluntary Aid Societies (VAS) and private ambulance companies should provide ambulance staff and other emergency service personnel with sufficient training to enable rapid and accurate diagnosis of CO poisoning. This should include the provision of software within the ambulance control call-taking system to recognise the indicators of CO poisoning.

Recommendation 8

Mandatory reporting of CO incidences should be introduced for healthcare professionals. Reported data should then be collated by Public Health England and equivalent bodies in the devolved countries of the UK.

6.4. Carbon monoxide poisoning: emergency medicine

Dr Ed Walker, Emergency Physician, Calderdale Royal Hospital, Halifax
Dr Simon Clarke, Emergency Physician, at Frimley Park Hospital, Surrey (until December 2016), Hamad Medical Corporation, Doha, State of Qatar

Case Study 1

In 2011, a couple were found dead in their home by their son. They were overcome by carbon monoxide (CO) from a coal fire. Two days previously they had sought medical advice for dizziness; the husband had been diagnosed with an ear infection and the wife with syncope when they attended their local emergency department. They were sent home, where the fire continued to emit dangerous levels of CO which ultimately caused their death. It is likely that the CO from the fire had caused the dizziness.

Case Study 2

Twelve patients were admitted to hospital with CO poisoning. All had been at a shisha bar, smoking in a room situated in the basement. Ambient CO levels in the room, recorded by the fire and rescue service were 440ppm (WHO guideline 30ppm for one hour). Resulting actions were that Public Health England (PHE), the local council and fire and rescue service worked to educate shisha bar owners, enforce health and safety and enforce fire precautions. This case study was then used as evidence for the development of the PHE Shisha Toolkit.

Emergency medicine is defined as a field of practice based on the knowledge and skills required for the prevention, diagnosis and management of acute and urgent aspects of illness and injury affecting patients of all age groups with a full spectrum of undifferentiated physical and behavioural disorders[1].

Recognition of CO poisoning is the key role of the emergency physician; unfortunately, this is extremely difficult because the clinical features of CO poisoning are non-specific and resemble a wide range of other, more benign conditions. Raising awareness amongst healthcare professionals has been advocated for a number of years,[2] but the case reports above clearly show that this is still a problem. Missing the diagnosis is likely to result in continuing exposure with the risk of long-term neurological complications[3,4], or even death.

6.4.1. Current knowledge and practice

6.4.2. Incidence

Research from abroad suggests that in an undifferentiated population of patients presenting to emergency departments (EDs), the incidence of CO poisoning is small but is higher in populations presenting with specific symptoms such as headache, dizziness, chest pain or flu-like symptoms. A study undertaken in four UK EDs (three urban, one suburban/rural) found unexpectedly high carboxyhaemoglobin (COHb) levels in 2.1%-7.5% of patients presenting with COPD, chest pain, seizures, flu-like symptoms and non-traumatic headache[4]. However, sources of exogenous CO were not identified in most of these cases, so confounding factors such as the patient not admitting to smoking could not be excluded. Thus the figures from this study should be interpreted with caution. However, two pertinent findings were reported by the study group:

- Non-gas sources of CO which are important, in particular from Shisha pipe smoking[5]
- CO poisoning is not seasonal and should be considered a possibility throughout the year: for example, poisoning can take place during the summer at festivals, on campsites and in boats

6.4.3. Diagnosis

[1] Royal College of Emergency Medicine , available from: http://www.rcem.ac.uk/RCEM/Patients/RCEM/Patients.aspx
[2] Walker, E. & Hay, A. 1999. Carbon monoxide poisoning. Br Med J, 319, 1082-1083
[3] Townsend C & Maynard, R 2002. Effects of health of prolonged exposure to low concentrations of carbon monoxide. Occup Environ Med, 59, 708-711.
[4] Clarke, S. et al. 2012[1]. Screening for carbon monoxide exposure in selected patient groups attending rural and urban emergency departments in England: a prospective observational study. BMJ Open, 2, e000877.
[5] Clarke, S. F. J., et al. 2012[2]. Multiple patients with carbon monoxide toxicity from water-pipe smoking. Prehosp Disast Med, 27, 1-3.

6.4.4. Clinical

Diagnosing CO poisoning is not easy: the symptoms of CO poisoning mimic those of other, more common ailments such as viral illnesses which can cause the classic 'flu-like symptoms' of headache, lethargy and muscle pains and, particularly in children, gastrointestinal upset[1]. Correct diagnosis requires a high index of suspicion.

'COMA'	
The mnemonic 'COMA' was devised to help identify those at risk of CO poisoning.[2,3,4] The mnemonic still requires validation.	
C	Co-habitees/ companions ('any co-habitees /companions with symptoms or signs including pets?')
O	Outside ('do you feel better outside?')
M	Maintenance ('have you had your fossil and wood fuelled appliances serviced recently?')
A	Alarm ('do you have a carbon monoxide alarm?')

6.4.5. Biomarkers

COHb is a well-known 'marker' of CO exposure; it is by far the most common way in which CO 'levels' in the body are expressed. The COHb measurement is given as a percentage – that number in turn being the percentage fraction of haemoglobin in the blood tested that is combined with CO at the time of testing. For purposes of illustration, a COHb of above 60% is usually incompatible with life; conversely a COHb of 3-4% may be regarded as 'normal' (small amounts of CO are produced by normal metabolic processes).

Like any clinical investigation, the results of COHb testing must be interpreted in light of the available history and clinical examination, and used as an aid to diagnosis and management – but it is not a silver bullet to diagnosis. An incidental finding of raised %COHb in someone who has just been hiking in the countryside and walked straight in to the ED is likely to be spurious; similarly a 'low/normal' result in someone brought in unconscious having been discovered in a room with three other unconscious people and a smouldering portable BBQ should not be relied upon.

A common misconception amongst healthcare professionals is that CO binds 'irreversibly' with haemoglobin. It does not. The compound decays once the victim has been removed from any CO source. An approximate 'half-life' of 4-5 hours breathing clean air (i.e. 21% oxygen at normal atmospheric pressure) is usually quoted. The rate of dissociation increases with increased partial pressure of inspired oxygen, and with increased rate and depth of respiration. Detailed 'back-calculations' to determine previous peak CO levels some time before are rarely helpful, unless in the most approximate terms.

The measurement of %COHb is not a sensitive test; a negative result cannot rule out CO exposure. Given its half-life, %COHb following a delay of only an hour or two before the blood test is taken, could result in a falsely negative %COHb level that inappropriately reassures both patient and clinician. There is variation in practice between EDs about how patients are initially assessed; some departments use an initial, rapid triage process whereas others use a slower but more in depth assessment system. The inherent delay in the latter increases the risk of a false-negative result. Non-invasive monitoring of %COHb for use in ED environments has been advocated to expedite %COHb measurement, but reliability and accuracy of the monitors has been questioned[5,6]. Until more accurate non-invasive monitors become available, venous blood gas analysis should be used in EDs.

Additionally, %COHb, whilst specific to CO exposure, is not sufficiently so to enable the identification of a source of CO (*eg* fossil fuel appliance vs cigarettes) or even increased endogenous production (*eg* haemolytic anaemia, pregnancy or as a result of exposure to methylene chloride).

[1] Walker, E. 2006. Carbon monoxide exposure: silent killer. The Independent. Available from: http://www.independent.co.uk/life-style/health-and-families/health-news/carbon-monoxide-exposure-silent-killer-422348.html
[2] Kar-Purkayastha , I., et al 2012. Low-level exposure to carbon monoxide. Br J Gen Prac, 62, 404.
[3] Walker, E. 2012. Carbon monoxide poisoning – are we doing enough? : http://secure.collemergencymed.ac.uk/code/document.asp?ID=6507
[4] Public Health England. 2013. Diagnosing Poisoning: carbon monoxide, available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/386214/CO_diagnosis_algorithm_StdQ_accessible.pdf
[5] Touger, M., et al. 2010. Performance of the RAD-57 pulse co-oximeter compared with standard laboratory carboxyhemoglobin measurement. Ann Emerg Med, 56, 382-388.
[6] Touger, M., et al. 2010. Performance of the RAD-57 pulse co-oximeter compared with standard laboratory carboxyhemoglobin measurement. Ann Emerg Med, 56, 382-388.

Exposure to tobacco smoke will cause %COHb levels to rise. However, it is not possible to determine the amount that smoking contributes to an individual %COHb result. %COHb levels in passive smokers are even more difficult to interpret. Clinical correlation between %COHb levels and outcome is poor. However, expired CO in the breath can be measured (with devices familiar to those who run smoking cessation services) and this result translated into a corresponding blood %COHb, usually by the device itself.

'Cherry Pink'

Cherry pink skin – the discolouration of mucous membranes sometimes observed - is *not* a common sign of carbon monoxide (CO) poisoning. COHb is a brighter hue than oxyhaemoglobin, which in turn is brighter than deoxygenated haemoglobin.

However, this is *not* a useful clinical sign. Its absence must never, under any circumstances, be used to 'rule out' possible CO poisoning. Someone sufficiently poisoned to have blood that is 'cherry pink', enough to be discernible to the average human eye, will certainly be unconscious, and probably be dead, but significant exposure is perfectly possible without this phenomenon appearing.

However, the colour of COHb has one vital impact on the emergency assessment of patients. Normal, two-wavelength pulse oximeters misread COHb as oxy-Hb: "if the patient looks pink to you, they look pink to a pulse oximeter." This means, reliance cannot be placed on 'normal' pulse oximetry when assessing patients from, for example, a house fire. Formal CO-oximetry, either by use of a pulse CO-oximeter, or by sampling venous, arterial, or capillary blood, is the only way to estimate the CO content of blood.

6.4.6. Treatment

High flow oxygen therapy should be administered on identification of poisoning; concentrations of 85% can be achieved using a well-fitting mask with a reservoir bag, while 100% concentrations require a non-invasive ventilation circuit or intubation and mechanical ventilation. HBOT remains controversial (see essay 7.5 on HBOT.) However, transfer distances may be prohibitively long for some EDs.

6.4.7. Follow-up

It is essential that emergency physicians contact the local public health services to ensure that the patient is followed up and all potential sources of exposure are identified and rectified. Public Health England has developed an algorithm for the management of CO incidents which includes details of services to contact to ensure that the patient does not return to an unsafe environment[1].

6.4.8. Training

Training in the diagnosis and treatment of CO poisoning is not covered routinely at undergraduate level in medical schools. Poisoning by CO is a part of the core curriculum for trainee doctors in emergency medicine, and is included in the Royal College of Emergency Medicine examination structure. However, it does not feature heavily as part of continuing professional development.

6.4.9. Ways forward: training and technology

Increased emphasis should be made on training in CO poisoning for both undergraduates and postgraduates to raise awareness amongst clinicians:

- Training should be multidisciplinary
- Patients who attend EDs with non-specific complaints such as non-traumatic headache, flu-like symptoms, chest pain and dizziness need to be asked a number of specific questions if CO is to be correctly diagnosed. The COMA acronym may be extremely useful
- Understanding the nuances in interpreting %COHb levels should be taught in more depth, especially the risks associated with false negative results
- Physicians need to be aware that patients who present with lower levels of %COHb were not necessarily exposed to CO in environments that can be considered safe or stable: low levels of CO can easily and unexpectedly increase to levels that are fatal

Venepuncture is recommended for %COHb measurements, although it would be useful not to have to rely on this method for confirmation of exposure (particularly as non-invasive testing is quicker and better tolerated

[1] Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/485581/CO_diagnosis_algorithm_2015.pdf

by patients, especially children). Currently, there are still significant questions about the accuracy of non-invasive tools that aid the diagnosis of CO poisoning and the use of therapies for its treatment. Technological development in this area has perhaps been underexplored given the advances in, for example, sensor development and diagnostic imaging.

6.4.10 Conclusions

Accidental, and therefore preventable, poisoning by CO exposure is probably more common than popularly realised; however, the extent of the problem is not known accurately.

If diagnosed, the hospital setting can provide appropriate treatment for CO poisoning; the problem lies with making a correct diagnosis. CO poisoning can be difficult to recognise, requiring a degree of vigilance by the ED staff. Case reports show that when it is missed as a diagnosis, consequences are often disastrous. Any screening procedure must be acceptable to patients and not add to the already large workload of EDs.

%COHb is a useful biomarker for the identification of acute high level CO exposure in patients tested at the scene of the source. But it becomes less helpful as the time between exposure and attendance at ED increases.

Public health units have well-established algorithms for management of CO exposures; communication between EDs and public health staff must be timely (i.e. as soon as possible after starting treatment of the index patient). Public health investigations not only reduce the risk of exposure to other members of the public but can help to confirm whether exposure has occurred in clinically uncertain cases.

Training in the diagnosis and treatment of CO poisoning is not covered routinely at undergraduate level in medical schools or at postgraduate level.

Recommendation 9

Emergency departments should adopt validated, rapid triage systems (*eg* Manchester Triage System) and combine this with the use of the COMA questions and early COHb measurement, together with targeted, rapid screening of specific groups of patients presenting at EDs, *eg* patients with dizziness, non-traumatic headaches, flu-like symptoms, seizures and chest pain.

Recommendation 10

Health Education England and the Academy of Medical Royal Colleges should support widely available and standardised training on CO poisoning throughout undergraduate and postgraduate medical training to raise awareness and improve diagnosis and treatment of CO poisoning.

Recommendation 11

To accelerate diagnosis of CO poisoning and the initiation of treatment, the Royal College of Emergency Medicine, the College of Paramedics and the joint Royal Colleges Ambulance Liaison Committee should lead the development of a COHb screening protocol and, with industry, a rapid standardised scene assessment procedure to determine indoor air CO levels, for use by emergency service personnel and by research scientists.

Recommendation 12

A prevalence study should be conducted to estimate the true cost of CO poisoning to the National Health Service.

6.5. Carbon monoxide poisoning: hyperbaric oxygen therapy (HBOT)

Dr Oliver Sykes, Consultant Anaesthetist, University College London Hospital and hyperbaric physician
Lee Griffiths, Independent Hyperbaric Technologist

Case Study

London ambulance service Hazardous Area Response Team (HART) are called to attend a 19 year old male working on a construction site who had been sitting in the rear of a work van with a small fuel powered generator.

The patient's work colleagues called 999 for an ambulance after opening the door to the van and finding that the patient had collapsed and appeared to start convulsing. The patient regained consciousness and was given standard onsite high flow oxygen therapy by a specialist HART paramedic, trained in carbon monoxide (CO) poisoning, recognition and treatment, who also carried out an onsite assessment of the patients neurological condition as well as general condition. Using onsite diagnostic equipment, a carboxyhaemoglobin (COHb) level of over 40% was detected in the patient and the paramedic contacted the duty consultant at the hyperbaric unit at Whipps Cross hospital. Both the consultant and onsite paramedic agreed that hyperbaric oxygen was indicated as the patient had a clear neurological deficit and that this was a severe acute poisoning.

The patient was transferred directly to the hyperbaric unit at Whipps Cross where he was immediately given a full neurological examination by the consultant and given an initial 1 hour 50 minute treatment of hyperbaric oxygen therapy at a pressure of 2.8 atmospheres absolute (ATA) within three hours of the incident. The patient was assessed afterwards and found to have no neurological deficit and was asymptomatic. After two more sessions of hyperbaric oxygen at 2.8 ATA the patient was discharged from hospital less than 24 hours after the initial accident. The patient was assessed at a follow up appointment with the same consultant eight weeks later and found to still be asymptomatic with no objective findings and no reports of relapse.

6.5.1. Current knowledge and practice

Once in the care of medical professionals such as paramedics or hospital doctors, the main form of treatment for CO poisoning is by breathing pure oxygen or as near to pure oxygen as possible (the air we breathe contains only around 21% oxygen). This can sometimes be called normobaric oxygen therapy (NBOT). NBOT is supplied at atmospheric pressure and can be high flow or lower flow, depending on the amount required.

However, hyperbaric oxygen therapy (HBOT) may be used to treat moderate to severe poisoning. The attending paramedic or doctor may decide to send the patient to a hyperbaric unit if the patient: is or has been unconscious; is pregnant; has problems with their heart (either caused by the poisoning or not); the poisoning is possibly affecting their brain (this may show as walking or balance problems as well as memory problems which may appear like dementia or drunkenness[1].

During HBOT, a patient breathes 100% oxygen intermittently while inside a treatment chamber at a pressure 2 to 3 times higher than sea level pressure for 90 minutes, up to 3 times within one 24 hour period. This is carried out in either a mono- or multi-place chamber. The former accommodates a single patient: the entire chamber is pressurised with 100% oxygen and the patient breathes the ambient chamber oxygen directly. The latter holds two or more people: the chamber is pressurized with compressed air while the patients breathe 100% oxygen via masks, head hoods, or endotracheal tubes. In both types of chamber, the aim is the prevention of long-term and permanent neurocognitive dysfunction, not enhancement of short-term survival.

[1] Davies SC, Beasley C. Carbon Monoxide Poisoning: Needless Deaths, Unnecessary Injury [Letter]. On line: Department of Health; 2010 [12.05.2013]: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/147681/dh_121501.pdf

6.5.2. Current advice

Current advice is to follow the Public Health England (PHE) incident management guideline if CO poisoning is the obvious diagnosis[1] or the PHE algorithm to aid diagnosis[2] and - if CO poisoning is diagnosed - then to follow National Poisons Information Service (NPIS) advice. According to TOXBASE®, NPIS does not recommend HBOT, despite recognising that myocardial injury and neuropsychiatric sequelae can occur. Therefore, toxicologists have recommended HBOT for CO poisoning on a case by case basis and local poisons information services are available to discuss it.

However, there is no protocol for the duration of administration of normobaric oxygen therapy (NBOT) (either minimum or maximum), as this is not known, nor is it known whether NBOT prevents long term neurocognitive sequelae[3] or even that it relieves acute symptoms.

The Chief Medical Officer also recommends the use of HBOT on a case by case basis: in pregnancy and in cases resulting in any loss of consciousness, neurological deficit, cardiac ischaemia or arrhythmia[4], although the debate about the added value of using HBOT is acknowledged. NICE has not produced guidance on the use of HBOT and the 2011 Cochrane Review[5] stated that more research was required before a confirmation on the efficacy of using HBOT could be confirmed or refuted. However, Healthcare Improvement Scotland does recommend HBOT for cases of CO poisoning[6] and the US Centres for Disease Control and Prevention recommend the use of HBOT under certain conditions with treatment covered by Medicare[7].

6.5.3. Research

Whilst there have been a number of trials comparing HBOT and high flow oxygen, conflicting results continue to prevent clear conclusions being drawn. The comparison of study results are difficult when different methodologies; definitions of poisoning and neurocognitive sequelae; COHb measurement methods; treatment protocols; blinding; and patient selection methods are used. The only trial to satisfy CONSORT criteria was carried out by Weaver *et al*, in 2002[3]. Whilst results were in favour of HBOT, such a study needs to be repeated and perhaps adapted accordingly to address current research gaps and uncertainties regarding the use of HBOT.

6.5.4. HBOT safety issues

A British Medical Journal Review by Leach et al[8] stated that "The side effects [of HBOT] are often mild and reversible but can be severe and life threatening. In general, if pressures do not exceed 3 ATA (303 kPa) and the length of treatment is less than 120 minutes, hyperbaric oxygen therapy is safe." A yearly adverse event rate of 0.38 to 0.46% over 1,159,600 monoplace treatments in four years in the US[9] has been described. Minor problems include claustrophobia and tympanic membrane barotraumas; rare complications include neurological, pulmonary and optic oxygen toxicity[10]. All these complications are reversible. Life threatening complications are rare but include explosive decompression and fire in the chamber. Concerns about transfer risks are often cited as a reason not to provide HBOT, however, work in the USA has not supported this suggestion[11].

6.5.5. Ways forward: training and research

The definition of acute and chronic CO poisoning and a more specific definition of delayed neurocognitive sequelae is required to assist in drawing firm conclusions from studies on the efficacy of HBOT. Likewise, optimal HBOT treatment and research protocols and methodologies for measuring %COHb need to be improved.

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[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/522454/Carbon_monoxide_IM_PHE_050516.pdf
[2] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/485581/CO_diagnosis_algorithm_2015.pdf
[3] Weaver LK, Hopkins RO, Chan KJ, et al. N Engl J Med 2002; 347:1057-1067 October 3, 2002DOI: 10.1056/NEJMoa013121 Available from: http://www.nejm.org/toc/nejm/347/14/
[4] Davies SC, Beasley C. Carbon Monoxide Poisoning: Needless Deaths, Unnecessary Injury [Letter]. On line: Department of Health; 2010 [12.05.2013]: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/147681/dh_121501.pdf
[5] Buckley NA JD, Isbister G, Bennett MH, Lavonas EJ. Hyperbaric oxygen for carbon monoxide poisoning. The Cochrane Library. 2011 (4)
[6] Ritchie K, Baxter S, Craig J, Macpherson K, L. M, McIntosh H, et al. The clinical and cost effectiveness of hyperbaric oxygen therapy (HBOT). Online: Healthcare Improvement Scotland; 2008 [13.05.2013]. Available from: http://www.healthcareimprovementscotland.org/previous_resources/hta_report/hta_systematic_review_2.aspx
[7] https://www.medicare.gov/coverage/hyperbaric-oxygen-therapy.html
[8] Leach RM, Rees PJ, Wilmshurst P. Hyperbaric oxygen therapy. BMJ. 1998 Oct 24;317(7166):1140-3. PubMed PMID: 9784458. Pubmed Central PMCID: 1114115
[9] Beard T, Watson B, Barry R, Hutson C, S C. Analysis of adverse events occurring in patients undergoing adjunctive hyperbaric oxygen treatment 2009-2012. Undersea and Hyperbaric Medical Society, 46th Annual Scientific Meeting; June 13-15, 2013; Orlando, USA2013
[10] McCrary BF, Weaver LK, Marrs K, Miller RS, Dicks C, Deru K, et al. Hyperbaric oxygen (HBO2) for post-concussive syndrome/chronic TBI. Product summary. Undersea and Hyperbaric Medicine. 2013;40(5):443-67
[11] Weaver L, Haberstock D, Churchill S. Transport of Carbon Monoxide Poisoned patients enrolled in a randomized clinical trial [abstract] 2003. Available from: http://archive.rubicon-foundation.org/xmlui/handle/123456789/1359?show=full

The management of CO poisoning should be routinely incorporated into undergraduate and postgraduate courses. Research should focus on the significant gaps in the science needed to underpin the use of different treatment options and an integrated response between healthcare professionals dealing with CO poisoning is required.

6.5.6. Conclusions

There is continued debate over whether HBOT reduces neurocognitive sequelae. Whilst HBOT for CO poisoning is currently approved under certain circumstances, on a case by case basis, the review being undertaken by NHS England[1] suggests that there an urgent need for repeated and improved trials to answer many of the questions posed regarding the efficacy of HBOT[2]. In addition, some of the same questions faced regarding the use of HBOT also need answering in relation to the use of NBOT to assist in the development of assured treatment protocols, particularly as NBOT is likely to become the only treatment available for CO poisoning in England. Such research is required to enable appropriate training and treatment pathways to be developed and adhered to.

Recommendation 13

Research needs to be funded to produce rigorous evidence that confirms or refutes the role that HBOT has in the treatment of CO poisoning, in particular with regard to its effect on reducing the risk of developing long term neurocognitive conditions.

Recommendation 14

NICE and NPIS should consider the evidence generated by the research proposed in Recommendation 13 to establish whether HBOT should be included as a recommended treatment option for CO poisoning in terms of effectiveness, cost and availability across the NHS.

[1] At time of publication, the use of HBOT was under review by NHS England with the suggestion that HBOT would be removed as a recognised treatment for CO poisoning due to a lack of evidence on its efficacy and mechanisms of action

[2] NHS England Specialised Commissioning Team. Commissioning Statement (4th draft): Developing the Commissioning Statement for Hyperbaric Oxygen Therapy 2013 [25.06.2013]. Available from: https://www.england.nhs.uk/commissioning/wp-content/uploads/sites/12/2013/10/d11-p-a.pdf Barratt H. Critical care transfer quality 2000-2009: systematic review to inform the ICS Guidelines for Transport of the Critically Ill Adult (3rd ed). JICS. 2012;13(4):309-13.

6.6. Carbon monoxide poisoning: in pregnancy

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Case Study

In 2013, a 23 year old woman in her first pregnancy attended her first appointment with a midwife. As part of the routine checks a carbon monoxide (CO) monitoring was undertaken and her expired breath level was found to be 64 ppm. This woman reported being a non-smoker and could not understand this high reading. Her partner volunteered to be tested as part of this check as he was concerned she was smoking. His reading was 82 ppm. The woman had reported symptoms of headache and nausea during the last couple of weeks. These symptoms may have been dismissed as being symptoms experienced during a normal pregnancy.

We discussed their household appliances and asked that they make an emergency call to have their home checked. The emergency department (ED) was also contacted for advice. The couple attended the ED, where oxygen therapy was administered.

A gas engineer attended the home and found the CO levels readings to be above 200 ppm. The boiler was condemned. The couple did not have a CO alarm and were not aware of the dangers.

This lady went on to have a normal delivery of a healthy baby, however she suffered severe anxiety throughout her pregnancy due to concerns regarding the possible impact this exposure may have had.

Carbon monoxide (CO) screening is being undertaken at the first appointment with the midwife in many maternity services across England following the recommendations within NICE guidance; *Smoking: stopping in pregnancy and following childbirth*. The screening is undertaken primarily to identify women who smoke, to help them understand the risks of smoking to the pregnancy and to ensure prompt referral for specialist support to help stop smoking. This procedure has also identified women with raised CO levels caused by sources other than tobacco smoke. Adverse outcomes have been reported after acute CO poisoning in pregnancy: fetal and neonatal death, congenital malformations and neurological problems have all occurred in association with reported moderate to severe (loss of consciousness/coma) maternal toxicity. The data available suggest that an increased risk of adverse outcomes also cannot be excluded after less severe maternal poisoning or following low level chronic exposure in the absence of maternal toxicity. Some studies investigating chronic environmental *in utero* exposure to CO have reported associations with preterm delivery, low birth weight, congenital malformations, sudden infant death and neurodevelopmental problems.

6.6.1. Current practice

Current best practice is that all pregnant women are screened at their booking visit which takes place at approximately 8-12 weeks gestation. A breath analyser is used to record expired levels of CO in the woman's breath. If levels indicate a positive smoking status this is confirmed with the woman and an opt-out referral is made for stop smoking support. Higher than expected levels should alert the midwife to the woman having been exposed to CO from another source.

When high levels of environmental CO exposure are suspected action is taken by the midwife, often based on local protocols and information disseminated during training. Also, the *Test Your Breath* information card for pregnant women which was developed by the Smoking in Pregnancy Challenge Group[1] discusses the dangers of CO in pregnancy, including from sources other than smoking. This resource is available, free of charge, to all maternity units in England, to be given to every woman when she books her maternity care.

[1] The Smoking in Pregnancy Challenge Group was established in 2012 in response to a challenge from the then Public Health Minister to produce recommendations on how the smoking in pregnancy ambition contained in the Government's tobacco strategy could be realised. The Group, a partnership between the Royal College of Midwives and the Royal College of Paediatrics and Children's Health, the third sector and academia, presented their report and recommendations to the Public Health Minister in June 2013 and continues to meet annually to review progress.

NICE 2010- National Institute for Clinical Excellence. Smoking: stopping in pregnancy and following childbirth. [PH26] Available from: https://www.nice.org.uk/guidance/ph26?unlid=69412261420169634 50
NICE 2012- Antenatal care for uncomplicated pregnancies. Clinical guideline [CG62] Available from: https://www.nice.org.uk/guidance/cg62
Smoking cessation in pregnancy- A call to action. 2013. Available from: http://www.smokefreeaction.org.uk/SIP/
Smoking in Pregnancy Challenge Group resources – Test your Breath (information for pregnant women) http://www.smokefreeaction.org.uk/SIP/
UKTIS – Exposure to carbon monoxide in pregnancy. Available from: http://www.medicinesinpregnancy.org/bumps/monographs/EXPOSURE-TO-CARBON-MONOXIDE-IN-PREGNANCY/

In some parts of the country a midwife can refer women to the fire and rescue service for a free fire safety check and the provision of smoke alarms. This arrangement is not in place across the country and does not always include a check for CO or provision of a CO alarm.

6.6.2. Ways forward

As more women are screened for exposure to CO at the beginning of their pregnancy, a concern is being highlighted about how to best identify pregnant women who are being exposed to high levels of environmental CO or are at risk of CO poisoning. It is essential that the scale of this problem is understood, the appropriate interventions are developed and agencies that need to act to better protect families are identified.

There may also be a need to develop guidelines on the management of CO poisoning during pregnancy.

6.6.3. Conclusions

Women need to be given every opportunity to discuss the impact of smoking on the pregnancy and to be referred for smoking cessation services, but they also need to be made aware of the importance of preventing CO exposure in their home in particular and of protecting themselves from CO exposure in general.

Reducing the impact of CO on women's pregnancy and children is paramount. By offering regular screening, relevant information for women and professionals, and developing appropriate pathways and interventions we will have more opportunities to assess CO exposure and reduce the risks to the unborn child and neonate.

Recommendation 15

A working group should be established to enable key organisations to develop a robust evidence-based pathway for the identification and prevention of exposure to environmental CO. These organisations would include: PHE, RCM, RCOG, Ofgem, HEE and NHSE along with academic colleagues and charities such as GST, SANDS, Tommy's and the Lullaby Trust.

Recommendation 16

Appropriate funding bodies should fund research in order to: provide a better understanding of the scale of environmental CO poisoning in pregnancy; establish the effects of repeated low dose exposure to CO on the developing fetus; gain a better understanding of the barriers and facilitators to the identification of CO poisoning in pregnant women; understand how better to protect women from CO poisoning by the actions of health professionals and other agencies; and, provide better information to individuals to help them protect themselves.

6.7. The effects of carbon monoxide exposure on the brain

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Case Study 1

A middle-aged man, who lived alone in his mobile home, was found by friends in a confused, incontinent state. Initial signs included respiratory failure, cardiac ischaemia, hypotension, encephalopathy and a rash, whilst subsequent features included rhabdomyolysis, renal failure, amnesia, dysarthria, parkinsonism, peripheral neuropathy, supranuclear gaze palsy and cerebral haemorrhage. Despite numerous investigations including magnetic resonance cerebral imaging, lumbar puncture, skin biopsy, muscle biopsy and electroencephalogram a diagnosis remained elusive. Several weeks after admission, diagnostic breakthrough was achieved when the gradual resolution of the patient's amnesia, encephalopathy and dysarthria allowed an accurate history to be taken for the first time. The patient's last recollection was turning on his gas heating for the first time since the spring. A gas heating engineer found the patient's gas boiler to be in a dangerous state of disrepair and it was immediately decommissioned.

Abstract from: Luke Bennetto, Louise Powter and Neil J Scolding. Journal of Medical Case Reports 2008, 2:118.

Case Study 2

A 45 year old woman suffered chronic exposure to carbon monoxide (CO) in the restaurant kitchen where she worked. It seems likely that she was exposed to CO at work for at least one year. Initially, she began to experience vague flu-like symptoms. Later, she couldn't walk straight and kept bumping into things. She had problems with balance, experiencing some falls and had a severe headache most of the time when she was at work. She felt an overwhelming sense of fatigue and a cloudy feeling in her head. She began to have difficulty speaking clearly or producing a full sentence. She had hearing problems, facial pain and became quite irritable. She felt better after five days off work. The maintenance engineers found that the furnace had a faulty ventilation system and a very high level of CO was found in the kitchen.

She was subsequently seen in the local emergency department (ED) but nothing significant was found on examination. After the furnace was fixed, most of her symptoms resolved. However, she did not completely return to normal: about 17 months later she was seen by a neuropsychologist. Her performance was in the superior range on most tests with a Full Scale IQ of 132, a Verbal IQ of 135 and a Performance IQ of 121. However, her performance was below expected on some demanding tasks involving attention, new learning, and memory retrieval. She had residual problems with speaking, reading, and writing: sometimes missing out a letter when writing a word. She had some difficulties finding the right word and would mispronounce words. A mood inventory suggested significant depression.

An MRI taken 15 months later was declared normal by a neurologist. However, a neuroradiologist and neuroscientist working in neuroimaging research who reviewed the scan felt that there were subtle changes in the basal ganglia consistent with CO poisoning.

A second neuropsychological evaluation 29 months after the end of her exposure to CO showed variability, with some scores better than those previously determined and some worse. However, she was still performing below the expected level on more demanding memory tests and on complex verbal reasoning tasks. She had poor performance on tests involving motor co-ordination and speed. It was clear that there were persisting subtle, but significant, cognitive impairments, still present more than 2 years after her exposure to CO had ended.

Précised from: Sherral Devine[1], Shalene Kirkley, Carole Palumbo, Roberta White
MRI and neuropsychological correlates of carbon monoxide exposure: a case report.
Environmental Health Perspectives 2002 110: 1051-1055.

[1] Devine S, Kirkley S, Palumbo C, White R, MRI and neuropsychological correlates of carbon monoxide exposure: a case report. Environmental Health Perspectives 2002 110: 1051-1055

Case Study 3

A 49 year PhD scientist noticed problems following maintenance work on his central heating boiler. He started to feel unwell: the first symptom was headache. He also began to feel rather sleepy, under the weather and unsteady. He worked largely from home and as it was cold the heating was often on. Suspecting a problem, he had the boiler examined by gas engineers. It was found that the casing had not been replaced correctly following earlier maintenance work. He was exposed to CO from the faulty boiler for about one week.

Once the boiler was fixed, he seemed to improve, but felt worse again after a few days. He had a headache, felt nauseated and foggy. He became unsteady and found that his concentration was impaired, so that he could only work for an hour or two each day.

About one month after the CO exposure, he arranged to see a neuropsychologist for a cognitive assessment. He did quite well on assessment, but subjectively felt that he was making use of some idiosyncratic coping strategies, to try and compensate for difficulties he was finding in completing some of the tests. An MRI scan with hippocampal volume measurements was considered normal.

Having researched the literature on CO poisoning, he arranged for some hyperbaric oxygen therapy (HBOT). He had 11 HBOT sessions over the next month. He felt there was some initial improvement, but this plateaued prior to the final session.

Four months after the original CO exposure, he felt that he was gradually improving: he was working again, although his concentration would begin to fade after about 10 minutes. His short-term memory was impaired and he sometimes had difficulty in thinking of the right word. He would sometimes forget things he had done: he might put the kettle on, but have no actual recollection of doing so. He was unable to interconnect things and integrate them in his head in the usual way. He struggled to manage conference calls. Whilst people at work had not commented on any problems, he felt that his work quality and output were not up to his usual levels and compensated for this using a variety of coping strategies. He was more anxious and irritable than usual, but coped by consciously modulating his behaviour. He was intolerant of noise and would easily feel over-stimulated if he was outside in an everyday environment.

One year after the CO exposure, he showed continued gradual improvement. Problems persisted with short-term memory, although his attention span was considered good. He felt that his general resilience was increasing and that he was back to his normal work output, although with extra effort. He was still more irritable than usual and looked forward to being by himself.

Nearly four years after the CO exposure, he feels 95% back to normal. He remains susceptible to some of the problems originally described, particularly if tired or stressed. He has come to accept that these subtle changes may be permanent, but is glad that he has returned to being able to carry on with his normal life with only minor residual difficulties.

This précised case history is included with the patient's permission.

Case Study 4

A 50 year old woman was admitted to hospital in Bangkok. During a trip to the United States, the family had stayed in a small hotel and were exposed to CO poison from a mobile heater in the room. The patient, her husband and her daughter were all found unconscious in their room. The patient was the most severely affected. She was admitted to intensive care and given several sessions of HBOT. She did well and was discharged from hospital after five days and returned to Thailand. She felt well again and went back to work. However, two weeks after returning home, she was found mute and unresponsive. On arrival at hospital, she was conscious but apathetic, uncooperative and not speaking. She was confused, disoriented and incontinent of urine. Her upper limbs were spastic and she showed abnormal choreiform movements. Her MRI showed white matter changes over both hemispheres and abnormal signal changes in the basal ganglia. The EEG showed generalised slowing and a brain SPECT scan showed multiple areas of reduced blood flow. She was given three more sessions of HBOT. She was in hospital for eight weeks and gradually improved. Her MRI showed a corresponding reduction in the white matter changes.

Précised from: Toungrat Tapeantong[1], Niphon Poungvarin.
Delayed encephalopathy and cognitive sequelae after acute carbon monoxide poisoning: report of a case and review of the literature. Journal of the Medical Association of Thailand 2009 92(10): 1374-1379.

[1] Tapeantong T, Poungvarin N, Delayed encephalopathy and cognitive sequelae after acute carbon monoxide poisoning: report of a case and review of the literature. Journal of the Medical Association of Thailand 2009 92(10): 1374-1379

Individual case histories can give a good insight into the problems which people may experience after carbon monoxide (CO) exposure. Although there is no specific pattern of neuropsychological impairment, the majority of studies describe problems with:

- Memory
- Visuospatial function
- Executive function (frontal lobe impairment)
- Speech, language, reading and writing
- Attention and cognitive processing speed
- Co-ordination and fine motor control
- Fatiguability

It is believed that the hippocampus, a brain region important for memory function, may be particularly susceptible to long-term damage from CO poisoning. Areas in the anterior and medial temporal lobe, insula, inferior frontal lobe and cingulate gyrus, involved with the modulation of mood and behaviour may also be damaged. Changes in memory and cognition are emphasized in much of the published work on CO poisoning. However, neuropsychiatric and neurobehavioural changes are also common, including:

- Depression
- Anxiety
- Irritability
- Aggression
- Lability of mood
- Personality change
- Impaired social perception
- Loss of social skills

6.7.1. Current knowledge and practice

Case 1 highlights several important issues: the bewildering myriad of clinical features of CO poisoning, the importance of making the diagnosis even at a late stage and preventing the patient's return to a potentially fatal toxic environment, and the paramount importance of the history in the diagnostic method.

Case 2 gives a very clear picture of the subtle but significant neuropsychological problems that can follow chronic CO exposure and highlights several important points:

- A routine neurological examination may be normal in people who show quite significant cognitive and neurobehavioural changes following CO exposure.
- Comprehensive neuropsychological evaluation is an essential part of the assessment after CO exposure.
- Subtle neuropsychological impairments may persist after chronic CO exposure.
- Subtle changes found on MRI following CO exposure may be overlooked in routine reporting of scans.
- Many people who do have normal imaging still have significant neuropsychological impairment.

Case 3 is very characteristic of people who have suffered mild domestic exposure to CO. It illustrates the occurrence of quite subtle cognitive changes after CO exposure and their potential impact on higher level functioning. The symptoms described are typical and the experience of an apparent initial improvement followed by persistent problems is familiar. The residual symptoms following CO exposure may seem rather nebulous, but represent an organic neurological syndrome with a characteristic symptom profile.

A delayed disturbance of brain function following acute, high-dose CO exposure, as reported in Case 4, is well recognised. The clinical manifestations of this condition are varied and include confusion, cognitive impairment, mutism, incontinence, disturbance of gait, limb spasticity and abnormal movements. Recovery from delayed encephalopathy after CO exposure has been reported as occurring in 50-75% of cases by one year[1].

[1] Choi I S, Delayed neurologic sequelae in carbon monoxide intoxication. Archives of Neurology 1983 40: 433-435

The long-term outcome from CO exposure can be quite variable, with differences between individuals reflecting the level and duration of exposure. Overall, the long-term prognosis following mild CO exposure is quite favourable. However, the time course of recovery is much longer than is usually recognised. It is often assumed that symptoms will resolve rapidly once exposure has ended. However, it has become clear that significant residual symptoms, particularly in the cognitive and neurobehavioural domains, may persist for 12 months or more and may even be permanent. The longer-term difficulties following mild-moderate CO exposure are still not widely recognised. This can lead to people who have been affected feeling isolated and alone with their problems as even 'mild' residual disturbances in memory, executive function, mood, personality and social behaviour may have devastating consequences for reintegration within the family and return to employment. This is very clear from work in other areas of acquired brain injury research, particularly traumatic brain injury.

All specialist neurorehabilitation units will see occasional patients with severe neurological deficits after acute CO poisoning, most of whom will have been unconscious. In this setting, recovery may be incomplete with long-term neurological problems that can prevent a return to normal independent living. However, a more frequent situation is where milder CO exposure is followed by more subtle cognitive and neurobehavioural impairments.

There are some NHS toxicology departments that may be able to provide elements of support, with access to neuropsychology, but they are generally unable to provide a more specialised and comprehensive long-term service for people following CO exposure.

6.7.2. Ways forward

There is an urgent need to increase awareness of the long-term cognitive and neurobehavioural effects of mild to moderate CO exposure amongst GPs, neurologists and psychiatrists, who may all see people who have been affected.

Recognition by healthcare professionals that a normal general neurological examination or routine MRI scan does not preclude significant disturbances of cognition, mood and behaviour in someone with confirmed CO exposure is critical.

Although existing neurorehabilitation services may care for people with severe CO exposure, there is very limited support for those with milder, persisting problems, particularly following chronic, lower level exposure. Specialist clinic-based services for CO exposed patients are required. Such services are well established within neurology for epilepsy, multiple sclerosis, Parkinson's disease and dementia. They have been shown to work effectively in terms of cost, resource utilisation and service delivery.

6.7.3. Conclusions

The brain is particularly susceptible to CO poisoning. Neurological and neuro-psychological injury accounts for the majority of CO related morbidity and disability.

The importance of neuropsychiatric changes following CO exposure is very clear from case study reports. Professor Malcolm Lader's series of more than 50 medico-legal cases[1] clearly illustrates this.

In some instances, the behavioural changes may be a central feature and can have an extremely disruptive effect on daily life.

CO exposure is not sufficiently common compared to other neurological insults (such as traumatic brain injury) for any one neurorehabilitation unit to build up an adequate experience of the complex profile of problems that may arise. Nor is CO exposure a unitary entity. A specialist unit is needed to develop adequate expertise to deal effectively with the range of long-term problems seen following CO exposure.

[1] Lader, M, Neuropsychiatric complications of carbon monoxide poisoning. Psychiatry 2009 20(1): 1-7

Recommendation 17

The Royal College of GPs, the Royal College of Psychiatrists and the Royal College of Physicians should collaborate to raise awareness amongst GPs, neurologists and psychiatrists on the long-term cognitive and neurobehavioral effects of mild-moderate CO exposure. GPs should consider CO poisoning as a potential cause when treating patients presenting with chronic neuropsychiatric complaints.

Recommendation 18

NHS England should develop specialist referral clinics to support and treat people with persisting mild-moderate cognitive and neurobehavioral problems following confirmed CO exposure. This will improve both treatment and the understanding of the profiles of chronic CO exposure in individuals, and improve the availability of mental health services that are required to treat patients exposed to CO.

6.8. Carbon monoxide poisoning: gaps in scientific knowledge

Dr Robert Dickinson, Senior Lecturer in Anaesthetics, Department of Surgery & Cancer, Imperial College London

6.8.1. Carbon monoxide poisoning

There are approximately 4000 identified cases of accidental carbon monoxide (CO) poisoning in England and Wales each year which require treatment but not admission to hospital, according to Department of Health statistics. In England and Wales, each year 200 patients are admitted to hospital with serious injuries and more than 30 people die as a result of accidental exposure to CO in the UK. It is estimated that CO poisoning costs the UK up to £ 178 M each year[1]. However, the number of people who are exposed to CO that remain undiagnosed and undetected is unknown. Studies indicate that the identified cases of CO toxicity may represent only the tip of a hidden iceberg. A study of 22,831 homes in East London fitted with CO alarms in 2011 - 2012 recorded 106 alarm activations, an incidence of 0.46%[2]. If this incidence is reflected throughout the UK, the number of potentially dangerous CO exposures may be very large. The figures are particularly concerning given that ownership of CO alarms is low: a survey of 22,000 homes by Merseyside Fire Services found less than 10% of homes had a CO alarm[3]. Another study of 1758 patients at four EDs in England found that 4.3% of those presenting with non-specific symptoms such as chest pain, headache, seizures or flu-like symptoms had elevated levels of carboxyhemoglobin[4]. These studies suggest that a large number of people may be being exposed to lower level but potentially harmful levels of CO. If these figures are representative then the number of people exposed to potentially harmful levels of CO that are currently undiagnosed may represent a silent epidemic of huge proportions. The social and economic implications of low level, undiagnosed, CO exposure may be substantial and there is an urgent need for fundamental research on the effects of low level CO on the brain.

6.8.2. Carbon monoxide toxicity

CO binds to haemoglobin 210 times more tightly than oxygen, reducing the oxygen carrying and oxygen delivery capacity of the blood. This causes reduced oxygen delivery to organs including the brain, resulting in a hypoxic brain injury, which may cause unconsciousness or death. Those that survive acute CO poisoning can also develop brain injury days or weeks after the exposure. The delayed onset of these symptoms suggests that CO has specific effects on the brain beyond acute hypoxia. Two recognised clinical syndromes associated with CO poisoning are persistent neurological sequelae (PNS) occurring immediately after exposure and delayed neurological sequelae (DNS) occurring days or weeks later (see Neurology essay above). The signs and symptoms of PNS and DNS range from disorders of mood and memory impairment, to severe locomotor or gait abnormalities[5,6]. It is important to recognise that these syndromes are the result of permanent brain damage caused by CO exposure.

The precise mechanism(s) underlying brain damage following exposure to high levels of CO (0.25-1%) are not fully understood, but it is believed that glutamate excitotoxicity, mitochondrial dysfunction, oxidative stress and inflammatory processes play important roles in an injury cascade that ultimately results in brain cell death[7,8,9]. As noted above there are significant differences between CO-toxicity and hypoxia[7]. Notable differences in the pathology of CO-poisoning and hypoxic injury are: brain damage can occur with low level CO exposure that does not cause loss of consciousness; CO-toxicity is characterised by so called Delayed Neurological Sequelae (DNS) occurring days, weeks or months after exposure. These pathologies are not seen under hypoxic conditions in the absence of CO. The clinical features of DNS have characteristics in common with neurodegenerative conditions such as Parkinson's or Huntington's disease, leading to the idea that other toxicological mechanisms are involved. Since the discovery that CO is an endogenous signalling molecule produced by heme oxygenases, and that CO interacts with nitric oxide (NO) signalling, it has become clear that CO has numerous other effects such as increasing reactive oxygen species (ROS), potentiating glutamate-

[1] All Party Parliamentary Gas Safety Group, Preventing Carbon Monoxide Poisoning, 2011
[2] McCann LJ, Close R, Staines L, Weaver M, Cutter G, Leonardi GS. Indoor carbon monoxide: a case study in England for detection and interventions to reduce population exposure. Journal of environmental and public health. 2013;2013:735952
[3] Merseyside_Fire_&_Rescue_Services. Merseyside Fire & Rescue CO study, available from: http://www.merseyfire.gov.uk/aspx/pages/rss/LatestRssPortalaspx?id=427.%202012.
[4] Clarke S, Keshishian C, Murray V, Kafatos G, Ruggles R, Coultrip E, 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)
[5] Weaver LK. Carbon monoxide poisoning. Critical care clinics. 1999;15(2):297-317, viii
[6] Weaver LK. Clinical practice. Carbon monoxide poisoning. N Engl J Med. 2009;360(12):1217-25
[7] Piantadosi CA, Zhang J, Levin ED, Folz RJ, Schmechel DE. Apoptosis and delayed neuronal damage after carbon monoxide poisoning in the rat. Exp Neurol. 1997;147(1):103-14.
[8] Thom SR, Bhopale VM, Fisher D, Zhang J, Gimotty P. Delayed neuropathology after carbon monoxide poisoning is immune-mediated. Proc Natl Acad Sci U S A. 2004;101(37):13660-5
[9] Thom SR, Fisher D, Zhang J, Bhopale VM, Cameron B, Buerk DG. Neuronal nitric oxide synthase and N-methyl-D-aspartate neurons in experimental carbon monoxide poisoning. Toxicology and applied pharmacology. 2004;194(3):280-95

receptor mediated excitotoxicity *via* NO signalling and activating inflammatory pathways. These pathways are over-activated in brain pathologies, neurodegenerative conditions and neurotoxicity, and are likely to play important roles in the pathological injury cascade that ultimately results in brain cell death following CO exposure[1,2,3].

One of the challenges facing healthcare professionals in both diagnosing and treating cases of CO exposure is the relative dearth of fundamental pre-clinical research to support an evidence-based medicine approach. As has been noted in other sections of this report, neurological and neuropsychological impairments are well described in patients who have been exposed to CO. However, specific mechanistic connections between CO exposure and the resulting cognitive and emotional symptoms are far from clearly established. Pre-clinical studies in animal models have played an important role in understanding the mechanisms underlying other types of acquired brain injury and are vital in understanding the effects of CO. Animal models allow the effects of CO on the brain to be studied under carefully controlled and reproducible conditions, which allows rigorous evaluation of potential treatment strategies and also allows mechanistic studies to be undertaken that may identify novel biomarkers.

6.8.3. Effects of sub-acute low level and repeated exposure to CO

The majority of pre-clinical and clinical studies of CO toxicity to date have focussed on acute exposure to high levels of CO. It is not known whether repeated sub-acute exposure to low levels of CO results in similar neurological and cognitive deficits. This is an important question because this pattern of exposure is most likely to occur, with people leaving and returning home to appliances that are malfunctioning. The use of animal models will play a key role in answering this question. Well characterised experimental paradigms exist to measure subtle changes in cognitive function, learning & memory and anxiety in rats and mice. These paradigms can be used to determine whether repeated exposure to the low levels of CO that may be produced by a faulty boiler will result in neurological symptoms. Another related research question is whether or not there is any lower limit to CO exposure that can be classified as entirely 'safe'. Given that the mechanisms underlying the neurological sequale of CO exposure are not fully understood, this currently remains an open question.

6.8.4. Injury mechanisms and biomarkers for low level and repeated carbon monoxide exposure

One of the great challenges in determining the effects of sub-acute, low level and repeated exposures to CO is that the mechanisms of brain injury after CO exposure are not fully understood. As mentioned above, the majority of studies to date have examined the effects of high level exposures (such as those causing unconsciousness or death). Those studies that have investigated the delayed onset of symptoms after single high level exposure may provide important clues to the effects of lower-level exposures. Nevertheless, it is far from certain that the same underlying molecular mechanisms apply to low level or repeat CO exposure. Investigating the effects of low-level CO exposure in an animal model at level of individual brain cells (eg using histological markers of injury) allows the mechanisms underlying injury to be determined and may lead to the development of better clinical biomarkers. Currently the only biomarker for exposure to CO is carboxyhaemoglobin (COHb) in the blood. As discussed elsewhere in this report COHb indicates that an exposure to CO has occurred recently but this is only detectable for a few hours after the exposure has ceased. The level of COHb in the blood decreases rapidly over the hours following exposure and eventually the signal disappears. If the original CO exposure level was low, then the COHb levels will more rapidly return to undetectable levels.

At present there are no reliable markers to show that CO exposure has occurred once %COHb levels have returned to normal. Therefore any clinical study aiming to investigate the effects of low level exposure to CO in a particular population, for example pregnant women, is hampered by the lack of a validated biomarker. The use of animal models is very helpful in identifying potential biomarkers because the level and duration of the CO exposure can be carefully controlled. In order to validate any biomarker it is necessary to establish that its presence correlates with exposure to CO, and it would be expected to change with different degrees of CO exposure. This involves identifying the presence of the marker at higher exposure levels and then quantifying the same marker at lower levels of exposure.

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[1] Piantadosi CA, Zhang J, Levin ED, Folz RJ, Schmechel DE. Apoptosis and delayed neuronal damage after carbon monoxide poisoning in the rat. Exp Neurol. 1997;147(1):103-14

[2] Thom SR, Bhopale VM, Fisher D, Zhang J, Gimotty P. Delayed neuropathology after carbon monoxide poisoning is immune-mediated. Proc Natl Acad Sci U S A. 2004;101(37):13660-5

[2] Thom SR, Fisher D, Zhang J, Bhopale VM, Cameron B, Buerk DG. Neuronal nitric oxide synthase and N-methyl-D-aspartate neurons in experimental carbon monoxide poisoning. Toxicology and applied pharmacology. 2004;194(3):280-95

It should be stressed that pre-clinical animal models can be used to validate a variety of different types of biomarkers of clinical relevance including:

- Biofluid biomarkers (*eg* blood, serum, urine, saliva)
- Imaging biomarkers (*eg* MRI/CT scans)
- Histopathological biomarkers (*eg* injury to specific brain cells types or areas)

6.8.5. Current treatments for carbon monoxide poisoning – improving the evidence base & novel therapies

The current treatment strategy for acute CO poisoning involves removal from the source of exposure, followed by oxygen therapy and supportive care. The elimination half-life of CO from haemoglobin is around 300 minutes in fresh air. Treatment with 100% oxygen at normal atmospheric pressure (NBOT) reduces the half-life to around 60 minutes, and oxygen treatment at increased pressure (HBOT) in a specialised pressure chamber reduces the half-life further[1]. Important questions remain regarding the more frequently used NBOT. While it is vital to displace CO from haemoglobin as soon as possible, questions remain regarding the optimum concentration of oxygen and the duration of treatment, as there is evidence from other types of brain injury that high oxygen (hyperoxia) for a prolonged time may exacerbate injury.

As discussed in another section, there are individual case-reports of HBOT improving symptoms after CO poisoning, but further research is required to determine the efficacy of HBOT. There are currently no clinically proven treatments following CO poisoning that specifically target the excitotoxic and oxidative stress cascades, or mitochondrial dysfunction that may result in delayed brain cell death underlying the long-term neurological problems. The use of animal models of CO toxicity allows for rigorous evaluation of therapeutic strategies under identical controlled conditions (eg the same CO exposure, identical treatment and time before the therapeutic intervention begins, identical treatment duration) which is not possible in a heterogeneous patient population. Such studies will provide an evidence base to inform and support current treatment options and may also identify novel therapeutic interventions that may be of value in future.

6.8.6. Key knowledge gaps

As highlighted here, and in other sections of this report, there are a number of areas where gaps in scientific knowledge exist, that need to be addressed by translational scientific research. Questions that could be most effectively addressed by pre-clinical work using animal models are listed below:

- Is repeated exposure to low levels of CO cumulative? Whether repeated exposure to sub-acute levels of CO results in similar neurological deficits as acute CO poisoning is not known. Given that it is known that acute CO poisoning can result in permanent brain damage, it is important to understand whether exposure to sub-acute low levels of CO also results in brain damage, and whether repeated exposures to low levels of CO has a cumulative effect resulting in brain damage.

- Identification of novel biomarkers for low level CO exposure. A major challenge in determining the effects of sub-acute, low level and repeated exposures to CO is that the only clinical biomarker for exposure to CO is blood COHb. The problems with COHb as a biomarker have been outlined above. Identifying effective and persistent biomarkers is vitally important for future research on low-level exposure. A substance in the blood or other body fluid following low-level exposure would allow effective clinical biomarkers to be identified, with the possibility that novel diagnostic technology could be developed. Identifying an *in vivo* imaging marker (MRI or CT) of low level CO exposure would also be of high relevance to clinical diagnosis of cases of low level exposure to CO toxicity in patients.

- Is there a safe low limit for CO exposure? The mechanisms by which acute CO toxicity leads to PNS and DNS are not clear. In the case of low-level exposure, the more diffuse symptoms such as anxiety or mood disorders and memory impairment may be missed or attributed to other causes (*eg* ageing or work stress). Identification of unequivocal clinical biomarkers of CO exposure would enable research on the effects of low-level exposure to be carried out.

- The effects of low-level CO exposure on particularly sensitive groups such as the very young and pregnant women are not well characterised. It is known that neonates and the unborn fetus are

[1] HBOT essay, section 7.5

highly sensitive to other forms of hypoxic brain injury that may result in lifetime morbidity, but the effects of low-level CO exposure have not been well characterised in these groups.

- What is the optimum concentration and duration for oxygen treatment? There is evidence from other types of brain injury that high oxygen (hyperoxia) for a prolonged time may exacerbate injury. This is a particular concern given that CO exposure increases levels of reactive oxygen species.

- Can we better assess the comparative effectiveness of hyperbaric oxygen and normobaric oxygen when both treatments are given under similar controlled conditions (*eg* CO concentration, duration and timing of treatment after CO exposure)?

- Are there additional treatments that could be given along with oxygen, or after oxygen treatment, that could limit the long-term brain damage resulting from CO exposure?

6.8.7. Conclusions

There is a need for more effective treatments for acute CO poisoning and for research into the effects of lower level exposure to CO, in particular where this exposure is repeated. Low level exposure to CO may be much more widespread than current figures suggest for the following reasons:

- It is unknown whether repeated exposure to CO is additive or cumulative.
- It is not known whether there is any safe low level limit for CO exposure.
- There are no reliable diagnostic tests or 'biomarkers' for low level sub-acute CO exposure.
- The clinical symptoms of non-lethal CO toxicity are non-specific and are easily confused with other medical conditions.

Clinical treatment of CO poisoning in patients is hampered by both a lack of understanding of the basic mechanisms and the absence of a solid pre-clinical evidence base on potential treatments and biomarkers. Pre-clinical studies using animals allowing standardised CO exposure, rigorous comparisons between treatments, and validation of biomarkers and would facilitate the translation of effective treatments and diagnostic strategies to clinical contexts.

As is the case in other types of acquired brain injury such as stroke and traumatic brain injury, pre-clinical research using reproducible animal models has an important role to play in the development of effective treatments. Animal models allow different treatment strategies to be evaluated under identical conditions, something that is not possible in a clinical population that is exposed to different (and unknown) concentrations of CO for different lengths of time. Careful control of the exposure is possible in animal studies and it is possible to measure outcomes both before and after exposure. In the clinical environment there are unlikely to be objective measures (*eg* cognitive tests) before and after exposure to low-level CO or a definitive unexposed 'control' group. Such experimental studies would also be of great assistance in the validation of putative clinical biomarkers.

Recommendation 19

Appropriate medical and healthcare funding bodies such as the Medical Research Council and Wellcome Trust - among others - should fund appropriate research on CO toxicity to explore the effects of low-level CO exposure and potential treatment options. Pre-clinical animal models allowing standardised CO exposure, rigorous comparisons between treatments, and validation of novel biomarkers, would provide an evidence base to underpin translation of effective diagnostic and treatment strategies to the clinic.

7. CONCLUSIONS

Accidental CO poisoning is a serious cause of death and disability in the UK. CO can affect people of any age and has various sources, from malfunctioning domestic appliances in winter to incorrectly used BBQs in summer, and from fumes from cars and lorries. High levels of CO exposure can be fatal within seconds, whilst low-level, repeated exposure may cause irreversible long-term damage, the extent of which is only beginning to be understood.

Patients who survive severe poisoning are known to suffer constraints to their daily lives for extended periods of time following the exposure. Certain groups are particularly vulnerable to CO poisoning, including the unborn child, older people, and those with a history of cardiovascular or neurological disease.

Healthcare professionals have a vital role in promoting CO safety, particularly in the diagnosis and treatment of CO poisoning and the prevention of ongoing poisoning. The general perception amongst healthcare professionals is that accidental CO poisoning is rare: unfortunately, it is not. The potential numbers of patients currently undiagnosed may represent a silent epidemic of huge proportions, with devastating social and economic costs.

Whilst there is still uncertainty surrounding the true prevalence of poisoning, confirmation of prevalence cannot be made without changes in levels of awareness of the possibility of CO poisoning and in the accuracy and reporting of poisoning diagnoses. In addition, our understanding of the long-term consequences of poisoning is limited and further work is required in this area.

The recommendations made in this report describe the steps that COMed Members consider must be taken. Turning these recommendations into action will involve government, the Academy of Medical Royal Colleges, bodies representing other health professionals, the third sector and other organisations.

COMed Members recognise that if healthcare professionals are to fulfil their potential in their role to protect, promote and maintain the health and safety of the public with respect to accidental CO poisoning, they must be given the opportunity to improve their knowledge on CO poisoning and be provided with the resources required to enable them to achieve this important goal. They advise that practices should be implemented that will result in:

- Improvements in awareness amongst clinicians and also amongst the public
- The application of robust protocols to enable healthcare professionals to respond effectively to suspected cases of CO poisoning
- A stronger evidence base to explain the short term and long term effects of CO on the body and brain, and on the value and effectiveness of potential treatments for cases of poisoning

To achieve this, Health Education England and other bodies, including the Academy of Medical Royal Colleges, should develop standardised training on CO poisoning throughout undergraduate and postgraduate medical education. The relevant Royal Colleges should raise awareness of CO poisoning amongst their members, with a particular emphasis on patient follow-up of the long-term cognitive and neurobehavioural effects of mild to moderate CO exposure. NHS England should establish specialist referral clinics to support and treat people with persisting neurobehavioural problems following CO exposure. Adopting these measures will increase clinical understanding of the effects of CO poisoning, enable healthcare professionals to identify more quickly the signs and symptoms of CO poisoning, and improve the mental health services required to treat patients exposed to CO.

In addition, robust protocols need to be put in place across the public services, to ensure that cases of CO poisoning do not go undetected. The residential inspection aid on CO produced by Public Health England and the Chartered Institute of Environmental Health should be reviewed, externally validated, and made accessible to all environmental health practitioners, to enable them to investigate the presence of CO in the homes that they visit. Screening protocols should be developed by the College of Paramedics and other bodies, with the input of industry, to enable the rapid identification of the presence of CO in homes visited by emergency service personnel. Enhanced training would also enable paramedics to spot the signs of CO poisoning more

quickly. The provision of indoor air CO monitoring devices for emergency service personnel, which would serve the additional function of protecting these workers as they enter potentially toxic environments, should be regarded as a priority. Meanwhile, emergency departments should adopt validated, rapid triage systems, combined with the use of the COMA acronym and the targeting of patients exhibiting symptoms traditionally associated with CO exposure, such as headaches, dizziness, and flu-like symptoms. In both pre-hospital and emergency department practice, diagnostic tools need to be developed to increase the rapidity of diagnosis: current non-invasive COHb or exhaled CO monitors need to be independently tested for their accuracy and reliability in the clinical environment. New biomarkers that are more stable and more informative than COHb alone need to be identified.

Robust research on the effects of potential treatments for CO poisoning must be undertaken to provide healthcare professionals with the confidence to act. In particular, research is needed to define the role that the different oxygen therapies might play in treating CO poisoning patients.

As has been underlined repeatedly throughout this report, collaboration between key organisations is vital if CO poisoning is to be dealt with efficiently and effectively. Additionally, medical and scientific research funding bodies should be encouraged to support studies to increase the knowledge base on the health effects, recognition and treatment of CO poisoning, with a particular focus on low level, chronic exposure.

In terms of measures that should be taken by public bodies outside of the healthcare sector to protect the public from CO, an early legislative priority is to require landlords in England and Wales to install CO alarms in all private and public rented sector properties that contain a fuel-burning appliance of any kind, not just solid fuel appliances as is currently the case. The review of the Smoke and Carbon Monoxide Alarm regulations for the private rented sector in England, which is scheduled to take place in October 2017, will provide a crucial opportunity for these amendments to the legislation to be made. In the meantime, action should be taken to ensure that those living and/or working adjacent to catering establishments are provided with CO alarms to prevent them being affected by fumes that may be emitted by cooking appliances and which can permeate through walls and ceilings.

In times of increasing challenges for the NHS and other public service bodies, carrying out these tasks will not be easy. Coordinated, collaborative action, as specified by the recommendations in this report, would provide a basis for the eradication of CO poisoning in the UK and also a model for how public services should tackle other public health issues in future.

If the recommendations made here are not acted upon, an untold number of people will continue to be at risk from CO poisoning. Those poisoned may have their lives devastated by a cause that could, in many cases, so easily have been prevented.

The recommendations made in this report, informed by the real experiences of healthcare professionals, could go a long way in raising awareness, stimulating the provision of appropriate resources, encouraging greater collaboration and strengthening the evidence-base on CO poisoning. If fully adopted, these recommendations will enable healthcare professionals to fulfil their potential to protect the health of the public from the threat posed by carbon monoxide, the silent killer.

8. CONTRIBUTORS AND ACKNOWLEDGEMENTS

Contributors

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Isabella Myers is an independent consultant with over 20 years' experience on the health effects associated with environmental hazards. Previously, Mrs Myers was a member of the Public Health England (PHE) Toxicology Unit at Imperial College, London, supporting the Air Pollution and Climate Change Group within PHE (previously within the Department of Health). Here, Mrs Myers was responsible for the development, implementation and support of health-based policies for government departments; led the scientific work on indoor air pollution; and coordinated the strategic approach to the protection of public health from the effects of CO poisoning.

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Dr Luke Bennetto is a consultant neurologist, neuro-ophthalmologist and senior clinical lecturer at the University of Bristol, who has published on a wide array of neurological topics including CO.

Dr Simon Clarke, MBChB DA FRCSEd FRCEM

Dr Simon Clarke is a consultant emergency physician with a clinical background in anaesthetics, general practice, and surgery. He worked at the Guy's Poisons Unit, Chemical Incident Response Service and Chemical Hazards and Poisons Division of the Health Protection Agency (now Public health England) between 2003 and 2012. Dr Clarke was chief investigator for an epidemiological study of patients with CO presenting to emergency departments in 2011 and has obtained funding for a follow-up study.

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Dr Robert Dickinson is a senior lecturer in anaesthetics in the Department of Surgery & Cancer at Imperial College London. Dr Dickinson works on translational medical research in the field of acquired brain injury using a variety of *in vitro* and *in vivo* brain injury models to evaluate potential clinical treatments and novel biomarkers. His research interests include traumatic brain injury, ischemic brain injury, and the effects of carbon monoxide on the brain.

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Kerri Eilertsen-Feeney has a BSc in Midwifery and over 11 years as a midwife. She is currently working as service transformation midwife, working towards improving and moving these services forward. Ms Eilersten-Feeney has previous experience of working as a community midwife and the introduction of the baby clear devices and the advice given to women regarding CO monitoring in pregnancy. Kerri is currently working towards her MSc in Practice Development Innovation.

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Lee Griffiths qualified as a hyperbaric technologist in 2005 and is a specialist advisor to the CQC for hyperbaric units. Mr Griffiths has a special interest in CO poisoning and has lectured on the subject for A&E units and special interest groups. He has also carried out training for NHS ambulance service HART teams and regional fire brigades.

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Andrew Humber joined the London Ambulance Service in 1986, became a clinical team leader in 2001 and then became a team supervisor on the Hazardous Area Response Team (HART) in 2006. Mr Humber has attended numerous incidents encountering hazardous materials and became overtly aware of the dangers of CO both to patients and the attending ambulance personnel. Mr Humber has undertaken a national feasibility study sponsored by the Department of Health in the pre-hospital monitoring of patients for CO poisoning.

Dr Gillian Jackson, BSc., Dip. Med. Tox., PhD.

Dr Gillian Jackson has worked for the National Poisons Information Service (NPIS) since 2007 and has been information services manager at the Edinburgh Unit since 2012, where she is a lead editor on TOXBASE®, the UK's online clinical toxicology database. Dr Jackson's current research interests include monitoring CO exposures reported via NPIS services. Dr Jackson became a member of CoMed in October 2016.

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Tony Lewis is a Chartered Environmental Health Practitioner, a Fellow of CIEH and is currently Head of Policy for the Chartered Institute of Environmental Health.

Prior to joining CIEH, Mr Lewis was employed as a Senior Lecturer in Environmental Health (specialising in environmental protection and health and safety) at Manchester Polytechnic, Nottingham Trent University and the School of Public Health Medicine at Nottingham University. Mr Lewis has also contributed to the Master of Studies programme in Public Health at Homerton School of Health Sciences at Cambridge University and has been a long-standing Associate Lecturer in Health and Safety Law at the University of Surrey.

Mr Bob Mayho

Bob Mayho was formerly principal policy officer in the policy team at the Chartered Institute of Environmental Health (CIEH). Mr Mayho has experience in a broad portfolio of policy areas including housing, climate change, animal welfare, pest management and the National Pest Advisory Panel, and local government reform.
Mr Mayho stepped down as a member of CoMed in January 2017.

Mr Steve Miller, CFCIEH

Steve Miller is a chartered fellow of the Chartered Institute of Environmental Health. He has been working in the field of Environmental Health for over 42 years, primarily in Local Government in London, and was head of regulatory services in the London Borough of Newham from 1997 to 2014. Mr Miller was chair of the then All Fuels Action Forum (now APPCOG Stakeholder Forum) and Advisory Board, stepping down in May 2017.

Dr Oliver Sykes, FRCA MBBS CHT

Dr Oliver Sykes is a consultant anaesthetist and has 15 years' experience in hyperbaric medicine, including the management of CO poisoning.

Dr Aravindan Veiraiah, MB BS MRCP(UK)

In 2010 Dr Aravindan Veiraiah became a consultant physician at the Royal Infirmary of Edinburgh and led the toxicology clinical governance team at the Royal Infirmary of Edinburgh for 5 years. Dr Veiraiah leads toxicology quality improvement projects aimed at standardising the management of drug-related agitation and at improving clinical risk assessment and monitoring in the toxicology ward. Dr Veiraiah has completed diplomas in Therapeutics and Toxicology at Cardiff University. Dr. Veiraiah stepped down from CoMed in October 2016.

Dr Ed Walker, MB ChB PGCert Med Toxicol

Dr Ed Walker is a senior clinical fellow and acting consultant in emergency medicine working in the Calderdale & Huddersfield NHS Foundation Trust. Dr Walker developed a particular interest in CO over twenty years ago, in particular how a toxin about which we apparently know so much continues to kill and harm at a truly alarming rate. Dr Walker is the lead on CO within the clinical toxicology working group of the Royal College of Emergency Medicine, and co-authored a publication last year outlining our current understanding of the neurotoxicology of CO.

Ms Hilary Wareing, SRN, RM, HV CERT

Hilary Wareing is the director of Improving Performance in Practice (iPiP) and the Tobacco Control Collaborating Centre (TCCC). She has a background in health service research and management as well as a clinical background as a registered general nurse, midwife and health visitor. Ms Wareing's main areas of interest are developing the wider public health workforce and supporting organisations to implement evidence-based practice and improve performance in practice.

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Dr Steven White is currently a consultant neurophysiologist at the Cromwell Hospital, London. His background is in neuropsychology, neuropsychiatry and EEG and he has a longstanding interest in cognitive and neurobehavioural changes following acquired brain injury.

About the APPCOG Stakeholder Forum and COMed

Formerly known as the Carbon Monoxide All Fuels Action Forum, the APPCOG Stakeholder Forum (the Forum) is a coalition of energy industry representatives, healthcare professionals, researchers, campaigners, and others committed to tackling CO poisoning in the UK. It is a leading, cross-party forum for Parliamentarians to discover, discuss and promote ways of tackling CO poisoning in the UK alongside the All-Party Parliamentary Carbon Monoxide Group.

The Forum promotes collaboration and knowledge sharing between industry, charities, parliamentarians and policymakers, as well as coordinating awareness-raising campaign activities across the sector. It provides a platform for key stakeholders to inform and influence public policymaking, improve safety standards, develop effective regulation, raise public awareness and, ultimately, help eradicate CO poisoning in the UK.

The report contains submissions from only selected sectors of the healthcare profession. This is due entirely to the current membership of the sub-group: no emphasis has been placed on these specialisms through any prior decision to downplay other healthcare specialties.

Until recently Steve Miller, an assembly member at the Chartered Institute of Environmental Health (CIEH) chaired the then Carbon Monoxide All Fuels Action Forum. The Forum is now chaired by Chris Bielby, director of industry liaison, SGN.

The Advisory Board provides recommendations to the Forum on its strategic direction and work, and performs a monitoring function by ensuring that the Forum is on track in relation to its vision and desired outcomes, including by ensuring good financial and management systems and controls.

The sub-groups of the Forum, including COMed, are specialised groups that conduct their own work programme as directed by the group membership, overseen by a nominated Chair who reports on sub-group activity to the Advisory Board and The Forum.

COMed - the Carbon Monoxide Healthcare Professionals Group - is dedicated to bringing together healthcare professionals including academics and researchers to tackle and prepare for the problems of CO poisoning. The group meets quarterly to co-ordinate activities and discuss developments in the healthcare sector on CO safety.

The Forum is administered by Policy Connect. Policy Connect is the collaborative, go-to cross-party think tank, successfully delivering new policy ideas through research, evidence, political meetings and sector engagement. With no set ideology, we recommend the best approach from facts and data, and help influence policy decisions and law-making.

We find the common ground and build consensus to improve public policy. We do this by running forums, commissions and All-Party Parliamentary Groups. We have overseen the research and delivery of more than 50 key publications.

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9. GLOSSARY & ABBREVIATIONS

ABG	Arterial blood gas
ATA	Atmosphere absolute
Biomarker	A naturally occurring molecule, gene, or characteristic by which, in this case, CO exposure and/or effects can be identified
CIEH	Chartered Institute for Environmental Health
CO	Carbon monoxide
COHb	Carboxyhaemoglobin
CMO	Chief Medical Officer
CNO	Chief Nursing Officer
ED	Emergency Department
EHP	Environmental health practitioner
Glutamate excitotoxicity	The process by which nerve cells are damaged or killed (in this case) by glutamate
GST	Gas Safety Trust
HBOT	Hyperbaric oxygen therapy
HEE	Health Education England
HES	Hospital Episode Statistics
HHSRS	Housing health and safety rating system
HPA	Health Protection Agency (now PHE)
Hypoxia/Hypoxic	An abnormally low level of oxygen: in the case of CO poisoning this is produced by a normal supply of blood which is deficient in oxygen
Ischaemic Heart Disease	Heart disease due to a reduction in blood supply to the muscle of the heart wall, caused by a reduction in blood flow through coronary arteries
ITU	Intensive Therapy Unit
NBOT	Normobaric oxygen therapy
NHSE	National Health Service England
NPIS	National Poisons Information Service
OFGEM	Office of Gas and Electricity Markets
PHE	Public Health England
RCM	Royal College of Midwives
RCOG	Royal College of Obstetricians and Gynaecologists
SANDS	Stillbirth and Neonatal Death Charity
SPCO	Carbon monoxide level in the blood
TOXBASE®	The primary clinical toxicology database of the NPIS
VBG	Venous blood gas
WHO	World Health Organisation

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