The efficient operation of regulation and legislation:

An holistic approach to understanding the effect of Carbon Monoxide on mortality

A Report for the CO Research Trust
February 2022

Abstract

A report identifying ways to improve the investigation of CO poisoning through Medical Examiner scrutiny and referrals to the Coroner

CO Research Trust
EVIDENCE • SAFETY • HEALTH

Isabella Myers BSc DIC MSc MRSB
Fellow (Nov 2016 - Nov 2017), Cranfield University, Shrivenham

Contents

The author would like to acknowledge and thank the attendees of the roundtable event and in particular Roland Wessling for their assistance in helping to frame this piece of work and for the helpful advice they provided. Their input is greatly appreciated.

Scope of the report

This report considers regulations and legislation, introduced by different government departments, that are designed to prevent CO exposure and to promote safe gas use. In addition, the report considers how Coroners and Medical Examiners in their currently non-statutory role, might assess deaths to improve the reporting of exposure to CO from unsafe practices or negligence, across both the gas and healthcare sectors.

The report provides: 1) recommendations that should be considered in the development of a robust framework for a multi-sectoral approach, 2) a narrative that should prompt further discussion and educational events with appropriate bodies, and 3) the advancement of scientific research and technological development to facilitate prevention and identification of exposure. The report covers a range of issues that are of central importance to reducing the effects of CO on public health. The discussion is intended to raise questions on specific issues related to the implementation and delivery of such a framework, and highlight gaps in data, practice and reporting.

Whilst the report is focussed on the production of CO from gas-fuelled appliances, it is accepted that other carbon-based fuels also produce CO and that much of the report will focus on the consideration of CO as a pollutant rather than its fuel source.

The literature on CO is broad, emergent in some areas, and developing rapidly in others. A systematic review of the literature has not been undertaken. Papers, reports, and information covering different components of CO exposure, such as health effects (covering different research disciplines), regulations, legislation, healthcare systems, and the role of industry have been considered, and relevant aspects studied to develop the narrative, questions, and recommendations.

Further work is recommended. It is clear that further evidence is required to develop views, encourage debate, and invite thorough consultation the issues raised within this report.

This study was undertaken to address a recommendation produced as a result of an All Party Parliamentary CO Group (APPCOG) inquiry in 2011, to determine what level of awareness of CO poisoning there was amongst a number of CO stakeholders. The inquiry revealed that there was a significant lack of awareness amongst healthcare professionals regarding exposure to CO at levels that were not immediately fatal. More recently, concern has been raised that developments in the scientific understanding of CO as an important factor in the cascade of events that resulted in death, meant that it was possible that Coroners were not identifying CO exposure as either an underlying factor or a contributor to the cause of death. It was concluded that these issues impacted on the accuracy of the recorded data, and therefore a true understanding of the prevalence and burden CO exposure had on public health. Members of the inquiry continued to call for an investigation that would improve the situation and facilitate a better understanding of the true prevalence of CO poisoning, with a particular focus on coronial investigations and the consideration of implementing mandatory COHb testing post-mortem.

Introduction

The scientific literature shows, unequivocally, that indoor and outdoor air pollution is an important determinant of mental and physical health and wellbeing. There is a large volume of scientific literature that reports the effects of air pollutants on health, and research continues to provide the scientific evidence that underpins policies to reduce exposure. Carbon monoxide (CO) is a pollutant found in both outdoor and indoor air. As an indoor air pollutant, CO is included in a number of regulations designed to protect people from exposure: at high levels, CO is lethal. Nonetheless, the scientific literature increasingly shows that exposure to lower levels of CO (those that do not immediately kill) can also trigger fatalities from diseases, primarily in people with underlying health issues. Deaths triggered by exposure to CO, but where CO would not be considered the immediate or primary cause of death, present an issue and reveal a mismatch with current regulatory and legislative frameworks that encompass safe gas work, the prevention of CO poisoning and the duties of H M Coroners. Though industry and other stakeholders acknowledge that illegal gas work (that carried out by unregistered gas fitters) is prevalent in the UK, if a death where CO has triggered or contributed to a death from another cause is not investigated and thus not recognised and reported, then gas fitters operating illegally are likely to evade the systems in place to protect occupant health and save lives. Likewise, hospital and community healthcare professionals must act on information they obtain that raises suspicion or confirms that their patient has been exposed to CO. Returning a patient to, or leaving a dependent patient in an unsafe environment should be regarded as negligent, thereby making a referral process between the healthcare sector and industry crucial. The absence of a joined up approach between accepted and developing scientific knowledge, medical diagnosis, Medical Examiner scrutiny, coronial investigation and the regulatory and legislative requirements of industry and government departments, creates a loophole that both perpetuates illegal gas work and produces a lack of accurate reporting of important public health data on the effects of CO poisoning-related deaths in the community and may lead to further deaths or cases of serious illness.

The effects of acute high level exposure to CO have been recognised for many years: at such levels, CO is likely to cause death; at lower levels, it was formerly not thought to cause significant harm to health because such exposures were thought to produce reversible effects. The effects were considered to be insignificant on the questionable basis that similar effects were produced by many other no-fatal conditions. CO poisoning has also been considered to be easy to treat: CO is removed from the body when air not containing carbon monoxide is breathed and more rapidly when oxygen is added to the inspired air. In some countries other than England hyperbaric oxygen is used to increase the rate of removal of carbon monoxide from the body.

However, the scientific literature indicates that chronic exposure to sub-lethal levels of CO can have effects on health, to the extent that those with underlying disease can have their health status worsened with an accelerated decline to death. In some cases, the triggering of an acute deterioration of health may cause sudden death. That this might occur in patients with impaired blood supply to the tissues of the heart seems self evident.

Preventing exposure to CO in the domestic indoor environment is largely left to the occupants or the owner of the home, although regulation and legislation exists across many government departments to ensure and promote the safe use of gas and other fossil fuels and the prevention of CO poisoning. Despite regulation, legislation and awareness campaigns, accidental deaths from CO poisoning still occur. It is widely accepted that the recorded incidents of death as a result of exposure to CO are unlikely to reflect the true numbers of people who die as a result of exposure to CO or from an underlying disease exacerbated by exposure to CO. Misdiagnosed or undiagnosed CO exposure can result in the patient being returned to the environment where poisoning occurred, dying, and the death being attributed

to an underlying health factor. If lower levels exposure to CO can trigger a cascade of patho-physiological effects leading to death, then it is self-evident that this requires investigation based on the regulatory and legal frameworks associated with gas use and CO. The questions: has the exposure occurred as a result of (1) poor engineering workmanship, (2) as result of a community healthcare worker not recognising the implications of a CO alarm sounding, or (3) as a result of a landlord using an illegal gas worker to check appliances and provide a false certificate, should be answered. There is currently no known safe threshold for environmental CO exposure: it is likely that people, dependent on their vulnerability are affected by differing levels and durations of exposure.

Industry figures indicate that, due to illegal gas work, there are over a million homes in the UK that have appliances that are either unsafe or immediately dangerous. It should also be noted that the source of the CO may not be in the property where the exposure occurs.

CO is also found in the ambient outdoor air and is a pollutant monitored as part of the EU Directive 2008 on ambient air quality. The Directive states that 'emissions of harmful air pollutants should be avoided, prevented or reduced'. Levels of CO in ambient air are far lower than those often found in indoor environments where exposure duration is also likely to be greater. With the current trend towards working from home, exposures from indoor sources are likely to increase unless a system to ensure safety is implemented.

The introduction in the UK of the Medical Examiner system in April 2019 and the changes to the notification of deaths to H M Coroners in October 2019, have the potential to facilitate closer consideration of CO as an underlying cause of, or contributor to death. By utilising government and industry regulatory requirements and legislative powers to assist healthcare professionals in their diagnosis of exposure to CO, fatalities in the community can be prevented. Likewise, Medical Examiners and Coroners can gather information and should work together with relevant government departments and industry to prevent illegal gas work and protect the families of patients to whose deaths continued exposure to CO has contributed or been an underlying factor.

If policies are to be effective and legislative requirements upheld, the requirement for a joined up, multi-sectoral approach to provide a framework for tackling the public health burden and avoidable mortality associated with accidental exposure to indoor sources of CO is of greater importance than has, perhaps, been thought.

Recommendations

1. A multi-sectoral group dedicated to the implementation of a framework for investigating and reporting incidents of lower level CO-related deaths, governed by HSE, should be established.

2. A dedicated Secretariat should be established to gather the evidence to support the work of the multi-sectoral group.

3. An impact assessment on the provision of a system to investigate lower level CO-related deaths should be undertaken.

4. An investigation of ICD-10 coding practices to facilitate more accurate recording of CO-related deaths should be undertaken.

5. The feasibility of developing, and the subsequent testing of a pathway to facilitate the reporting of CO exposures by relevant industry professionals to healthcare professionals for entry into a patient's medical notes should be investigated.

6. Gas Distribution Networks and Ofgem should work together to establish a 'duty of care notification' of gas appliance maintenance jobs that links to their vulnerable customers' GP records.

7. A memorandum of understanding between the HSE and The Chief Coroner for England and Wales should be developed to facilitate working practices in the investigation of lower level CO-related deaths in the community.

8. Guidance should be developed for Medical Examiners by a dedicated group of medical professionals and the Royal College of Pathologists, to assist them with scrutinising the chain of causation of death and recognising when lower level CO exposure might be implicated.

9. Improve awareness of CO amongst Medical Examiners, Coroners' pathologists and Coroners via collaborative educational symposia with the Royal College of Pathologists.

10. The production and provision of tested materials for training and educational sessions on CO for community healthcare workers and community midwives in conjunction with relevant professional bodies should be supported.

11. Guidance for reporting cases of suspected or known CO exposure by community healthcare workers and community midwives, should be developed to facilitate the scrutiny undertaken by Medical Examiners.

12. The innovation, development and implementation of technologies that can assist in deterring substandard and illegal gas work, and which link to an immutable time-stamped cryptographically secured database, should be actively pursued and supported.

13. The Medical Examiner database should record data on instances of Medical Examiner identification of lower level CO-related deaths and resulting referrals to the Coroner. Outcomes of coronial investigation of lower level CO-related deaths should be added to the database to facilitate linkages with industry data, ONS data and to inform public health research.

14. Coroners and pathologists should be made aware of new techniques that could be used in the post-mortem investigation of CO exposure that provide information additional to that provided by COHb levels found in blood.

15. Funding should be made available for researchers to work with pathologists to facilitate the use of minimally invasive techniques and the discovery of new biomarkers of effect that would aid investigation of high level and low level CO-related deaths. This would be particularly important in the consideration of coronial investigation of stillbirths [Dependent on the outcome of the consultation].

16. The development and improvement of equipment and techniques that can be used in the rapid and accurate detection of CO by registered gas engineers to reduce the delay in confirming exposure to levels of CO that do not result in CO alarm activation, but are suspected by healthcare professionals to be the cause of symptoms in their patients, should be supported.

17. A strategy for the renovation of homes in fuel poverty that includes 1) air quality standards set for those with underlying health conditions, that requires 2) a monitoring period to ensure that reduced ventilation, energy saving practices and building work have not affected indoor air quality and the functioning of fossil fuelled and wood burning appliances or their associated flues or chimneys, should be developed.

18. The research, evidence and knowledge-base must be developed and supported to improve the prevention and identification of CO as a potential underlying causal or contributory factor of deaths in the community.

Actions arising from the Roundtable

DATA

- The utility of Biobank data should be considered.
- Develop solutions to authenticated data capture on CO from multiple sources and ensure secure storage and access.

RESEARCH

- Research on the effects of CO exposure on cardiac and neurological damage needs to be further developed.
- Research is required into the effects of CO on the fetus and neonate.
- Toxicological research studying umbilical cord blood COHb vs maternal COHB should be taken forward.
- Urgent research is required on the levels of COHb in umbilical cord blood and fetal blood to provide the evidence base for raising an inquest on a stillbirth [if applicable pending outcome of the consultation 2019].
- Research is required to better understand the levels and durations of exposure to CO that could result in a neonatal death.

It was acknowledged that funding for research needs to be made available and a programme of research and innovation developed and supported to tackle CO.

EXPOSURE DURING PREGNANCY

- It was agreed that the data stored by each NHS Trust on CO should be accessed and analysed.
- It was suggested that the RCM should be given access to the CO data on pregnant women long term.
- It was noted that a referral pathway was required to assist hospital midwives, community midwives, and health visitors provide advice and direct women identified as potentially exposed to environmental CO to further services.
- Further research to inform the update of treatment protocols for pregnant women exposed to CO was required.
- Research to improve understanding of the impact exposure to CO has on the fetus at critical stages of development is needed.
- Understanding why the additional vulnerability associated with pregnancy and CO is not adequately addressed by government and industry needs to be investigated.
- It was agreed that investigation of CO exposure in-utero and by the neonate was an area that required urgent funding to provide evidence for healthcare practitioners and industry, and for the development of stakeholder solutions and interventions.

ACTIONS ARISING OUT OF DISCUSSION

- It was advised that once sufficient progress had been made on the topic, that the Death Investigation Group at the RCPath should be contacted for further input and discussion of improving guidelines on autopsy practice to highlight CO and organising joint training initiatives.
- It was advised that proposals should continue to be discussed with the Coroner's Office as work in this area progressed.
- The group should consider how best to use existing databases such as those from NHS Trusts and NHS Digital and the BioBank for further study of the impact of CO on deaths.
- Whilst steps are being taken to raise awareness of low level carbon monoxide monitoring, both among health professionals and in industry/utilities, analysis of data captured on CO needs to improve.
- Resuscitation practices and how these affect the reliability of Coroner's examinations should be considered.
- The role of district nurses and home-care providers in inquiring about potential CO poisoning in the homes of their patients should be developed.

Purpose of the report

When determining and recording the cause of death it is important to distinguish between proximate and antecedent causes. For example, the proximate cause of death might be a head injury due to falling down stairs but the antecedent or underlying cause might be loss of consciousness due to exposure to carbon monoxide. For some time, it has been suggested by some stakeholders that CO poisoning should be considered as an underlying cause of death on death certificates. Fatal incidents of CO poisoning, that are referred to the Coroner, are coded for on death certificates. In some cases, CO will only be mentioned in the narrative section of a death certificate. Where CO is mentioned only in the narrative section of a death certificate, the death will not be recorded as a death associated with CO poisoning in official statistical records of deaths. This suggests that official statistical records of deaths associated with CO poisoning underestimate the problem. Additionally, the scientific evidence for the patho-physiological effects of CO has developed and clearly shows that exposure to non-fatal levels of exposure (even more moderate levels of exposure) can both cause and accelerate a decline in health from an underlying condition or co-morbidity.

The prevention of exposure to CO in the UK is ensured by implementation of regulations specified by legislation. In the absence of accurate recording of CO as a cause of death it is impossible to say whether such regulations are adequate in terms of (1) their scope and (2) of the extent to which they are enforced. This report considers the current position of stakeholders involved in the upholding of regulations, preventing, and diagnosing deaths associated with CO and investigates how the development of scientific evidence might modify stakeholder actions.

In particular, it considers the effects of the introduction of Medical Examiners and reforms of death certification in England and Wales and the impact this might have on the identification of exposure to CO as an underlying cause or contributing factor to deaths. One of the tasks of Medical Examiners is the scrutiny of death certificates. This process will allow the detection of error and inappropriate recording on the part of healthcare professionals and should improve the quality of official death statistics. In cases where exposure to CO is suspected to have played a part in causing death, the case will be referred to the Coroner. Investigations carried out by the Coroner should lead to the identification of poor work by illegal fitters and malpractice by rogue landlords, prior to the requirement to refer the case to the Coroner. The aim of scrutiny of death certificates by Medical Examiners is to rule out malpractice by healthcare professionals. However, in the case of CO, this would also include the triggering of an investigation into malpractice by engineers or unskilled workers undertaking work on domestic fuel powered appliances and on rogue landlords.

It is not the purpose of this report to increase referrals of deaths to Coroners as this would run counter to the objectives of the introduction of the Medical Examiner system. It is the purpose of this report to suggest means by which deaths due, largely or in part, to CO can be identified and recorded. Such identification is essential, to prevent the exposure of others who may continue to occupy the environment in which the deceased was exposed.

The report seeks to develop an argument for the improved reporting of deaths where CO exposure is an underlying or contributing factor to death, and to provide recommendations to facilitate the development of collaborative work to enable better reporting and improved systems of investigation. These will assist in the development of interventions that support regulations, identify modifiable risk factors to improve public health and facilitate the collection of data for non-communicable disease surveillance and investigation.

BACKGROUND RELATING TO CO

Acute exposure to high levels of CO is well-known to cause death.[1] However, exposure to CO cannot be recorded as the immediate cause of a death on a death certificate. This is because the immediate cause of death must define a pathological process or event, for example heart failure due to myocardial infarction, respiratory failure from pneumonia. Therefore, CO can at most be recorded as an underlying cause of death, or noted in the narrative section on a death certificate as being implicated as a factor that contributed to the event or process that caused the death. The more recent scientific literature shows that low to moderate levels of exposure for greater durations that are not lethal has the potential to trigger, accelerate or worsen a number of diseases[2]. The scientific evidence, whist advancing, does show a number of gaps in our understanding of the mechanisms of interaction between the effects of CO and other causative factors associated with adverse health effects. The epidemiological evidence is not so well developed, though the usefulness of reports from case studies must not be overlooked.

As with other air pollutants, chronic and acute exposure to CO could have significant effects on public health and this report seeks to consider whether such exposure could be having a greater impact in initiating, accelerating or worsening diseases that cause death than is currently acknowledged. The unique system in the UK that regulates the safe use of gas and other carbon-based fuels provides an exceptional foundation for the integration of the work of healthcare professionals, engineers and related industry stakeholders to reduce the public health impact of CO exposure. The potential for joined up reporting pathways to assist with coronial and Medical Examiner investigations will also contribute to the prevention of the continued exposure of occupants following a death in the community brought forward by exposure.

CO EXPOSURE

Carbon monoxide is a toxic, colourless, odourless gas that is produced when carbon containing fuels burn with insufficient air. Death from carbon monoxide poisoning is usually associated with acute high level exposures that cause cardio-respiratory arrest. Carbon monoxide (CO) poisoning as a result of accidental exposure has been a known cause of death for centuries. In 1858, Claude Bernard provided the toxicological explanation for how CO causes death[3], with further explanation provided by JS Haldane in 1895[4] and subsequently his son JBS Haldane in 1927[5].

Sources of exposure in the indoor environment in developed countries include appliances that burn carbon containing fuels such as malfunctioning stoves, boilers, and room heaters when they malfunction, and from blocked flues connected to these types of appliance. Appliances which are working properly and are used in accordance with the manufacturer's instructions produce very little CO. However, appliance malfunction resulting in the production of CO at levels that can harm health, is likely to occur due to lack of maintenance, faulty installation or improper use. Improperly placed generators and BBQs are another source of indoor CO exposure. These should only be used outside in well ventilated areas. BBQs have been shown to produce high levels of CO, even when extinguished and cold to the touch following use[6]. Other activities such as tobacco smoking also result in exposure to CO. Shisha pipe smoking produces CO not only from the burning tobacco but also from the smouldering charcoal used as part of the smoking activity. The exhaust fumes from petrol and diesel powered vehicles are also be sources of CO (although this is reduced in vehicles fitted with catalytic converters once they reach their operating temperature). Products that contain methyl chloride, such as some paint removers, can also be considered as sources of CO. When methyl-chloride is inhaled or absorbed through the skin, it is converted into CO in the liver resulting in the same effects as poisoning from the inhalation of CO[7].

[1] Coburn R.F (Ed), Biological effects of carbon monoxide, Ann.Y.Acad.Sci, 1970, 174, 1-140.

[2] Rose et al, 2017, Carbon monoxide poisoning: pathogenesis, management, and future directions of therapy. Am.J.Respir.Crit.Care.Med 2017;1;195(5):596-606.

[3] Claude B., An Introduction to the Study of Experimental Medicine, Dover edition, Dover Publications Inc., 1957, This is a reprint of the first English translation of 1927, Published originally in French in 1865

[4] J.S. Haldane, The action of carbonic oxide on man, J.Physiol., 1895;18: 403-462.

[5] J.B.S Haldane, Carbon monoxide as a tissue poison, Biochem. J., 1927; 21: 1068-1075.

[6] Nyombi A. et al., Toxic emissions from smouldering combustion of woody biomass and derived char with a case study of CO build-up in an ISO container. Energy Sources, Part A:Recovery, Utilization, and Environmental Effects.2019 doi:10.1080/15567036.2019.1623348.

[7] NHS. Carbon monoxide. www.nhs.uk (accessed January 2020)

DEFINING AND RECORDING CO MORTALITY AND MORBIDITY STATISTICS IN THE UK

Causes of death are recorded using International Classification of Disease (ICD) codes, a classification system developed and maintained by the World Health Organization and used in around 117 countries worldwide. The system is currently in its 10th revision (ICD-10), although records considering underlying causes of death from CO poisoning were recorded using the previous revision, ICD-9. In the UK the Office for National Statistics (ONS) codes all of the causes of death mentioned on the death certificate using the ICD codes. From the list of causes mentioned on the death certificate, using automated ICD coding rules, the underlying cause of death is obtained. An underlying cause of death is defined by the World Health Organization as

- ***'the disease or injury that initiated the train of events directly leading to death, or***
- ***the circumstances of the accident or violence that produced the fatal injury (or poisoning)'*** [8]

CO itself is not recorded as a cause of death but can be identified if coded as an underlying cause of death. For this coding to be completed, specific terms from the death certificate are coded and using computer algorithms, the assignment of underlying causes are suggested. Deaths attributed to poisonings such as CO are considered according to the underlying cause of death and secondly by the nature of the injury.

The calculation of the UK's mortality rate for non-fire related, non-suicide exposure to CO, is based on the average number of 'accidental poisonings by other gases and vapours' (X47) and where the secondary cause of death was 'the toxic effect of carbon monoxide' (T58). In the UK, statistics on deaths collated from 2004 to 2017 show a gradual decline from around 40 deaths to the current figure of around 25 deaths in the UK from accidental CO poisoning[9].

Other statistical records of CO poisoning are reported to HSE under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) reporting requirements, where incidents involving gas are investigated, sometimes in conjunction with a Coroner's inquest. Common sources of exposure leading to death include room heating appliances and boilers that are malfunctioning or have not been serviced[10].

The UK National Poisons Information Service (NPIS) also collects data on CO poisonings through its referrals to the service. Information collected helps provide intelligence on CO poisonings, covering information provided to healthcare professionals over the phone, through TOXBASE website and through the UKTIS telephone service (that provides information on teratogens)[11].

All age groups are affected by exposure to CO, although males and older adults have been found to be most at risk[12]. Figures of hospital admissions and hospital episodes show that there are around 4,000 attendances at Emergency Departments (ED) and over 200 admissions per year[13]. Of these 4,000 attendances, 1,600 were brought by ambulance, of which 1,300 were responding to calls to someone exposed in the home. The domestic environment is a notable environment where exposure occurs.

[8] WHO International statistical classification of diseases and related health problems . 10th revision, volume 2, 5th Edition 2016. www.icd.who.int

[9] Cross Government Group on Gas Safety and CO Awareness, Annual Report 2017/2018, Published March 2019. https://www.hse.gov.uk/gas/domestic/cross-government-group.htm

[10] All Party Parliamentary Gas Safety Group, Preventing carbon monoxide poisoning, 2011. Policy Connect.

[11] www.npis.org

[12] Fisher DS et al., Fatal unintentional non-fire-related carbon monoxide poisoning: England and Wales, 1979-2012. Clin.Toxicol (Phila). 014; 52(3):166-170.

[13] Cross Government Group on Gas Safety and CO Awareness, Annual Report 2017/2018, Published March 2019. https://www.hse.gov.uk/gas/domestic/cross-government-group.htm

However, there is broad agreement that these figures, relating to the detection and diagnosis of CO exposure, do not represent the true figures of exposure and deaths associated with CO exposure[14]. The collected data on mortality from CO is considered an underestimate at a world-wide level due to the unreliability of primary data sources in many countries[15]. This is due to the difficulties in diagnosis and the requirements for reporting exposure to CO in causes of death.

The Cross-Government Group on CO and Gas Safety use ONS statistics to provide an annual figure for deaths caused by CO poisoning registered in that particular year. The figure is provided in their annual reports, and an average figure reviewed every 5 years. Figures for England and Wales include deaths of non-England and Wales residents.

AVOIDABLE MORTALITY AND SOCIOECONOMIC INEQUALITIES REPORTING

In February 2020, ONS published their first annual report using the new definition for avoidable mortality and in May 2020, published their first annual report on Socioeconomic Inequalities in England and Wales using the new definition.

"Avoidable mortality" is used to identify causes of deaths which might have been avoided had effective healthcare and public health interventions been available. Recently a new definition has been agreed internationally. The calculation is made using death registration data. The following terms are used:

Preventable mortality	causes of death that can be mainly avoided through effective public health and primary prevention interventions (that is, before the onset of diseases or injuries, to reduce incidence).
Treatable mortality	causes of death that can be mainly avoided through timely and effective healthcare interventions, including secondary prevention and treatment (that is, after the onset of disease, to reduce case-fatality).
Avoidable mortality	deaths that are preventable or treatable.[16]

These definitions are used to provide information on the impacts of preventative health care programmes and to allow the modification, as necessary, of such programmes. It is therefore of even greater importance that death certificates are appropriately coded and CO considered, particularly in the triggering of disease.

The Socio-economic reporting is important in the consideration of CO as there is a greater risk associated with CO poisoning in areas of higher deprivation.

Improved reporting will assist in providing more robust data and will better inform prevention interventions.

[14] All Party Parliamentary Gas Safety Group, Preventing carbon monoxide poisoning, 2011. Policy Connect.

[15] Mattiuzzi C et al, Worldwide epidemiology of carbon monoxide poisoning. Hum.Exp.Toxicol. 2020;39(4):387-392

[16] www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/causesofdeath/bulletins/avoidablemortalityinenglandandwales/2018#avoidable-mortality-data (accessed May 2020)

Medical Examiners database

A purpose-built Medical Examiners' database is being developed by the Department of Health and Social Care (DHSC), acknowledging that Medical Examiners can provide useful data to inform the development of national and regional public health policies as part of their scrutiny duties. The database is being developed in line with the piloting of the Medical Examiner system.

Medical examiners can provide useful statistical information at both national and local levels. Pilot testing of the Medical Examiner system has already accommodated local requests ranging from morbidity and mortality committees requesting outcomes of certification and investigation, to researchers interested in patterns and trends such as local deaths related to alcohol, thromboembolism or autoimmune hepatitis. The purpose-built Medical Examiners' database facilitates this.

HEALTHCARE PROFESSIONAL DIAGNOSIS OF CO EXPOSURE AND RESULTING DEATHS

The accuracy of reports of exposure to carbon monoxide and resulting deaths is questionable.

Poisoning by CO is difficult to diagnose unless the healthcare professional has a high level of suspicion that exposure to CO may have been the cause of the patient being in poor health, or poorer health than expected. The signs and symptoms of exposure are many and varied, and mimic those of illnesses more commonly encountered by healthcare professionals than cases of CO poisoning. Some of the most frequently reported symptoms of non-lethal exposure to CO can be attributed to influenza, food poisoning or infection. Symptoms also vary, many patients may present with headache, but others may not, even when exposed at levels and durations that would suggest that this symptom should have been reported. Chest pain is another common symptom. How a report of chest pain is likely to be investigated depends, in part, on the mode of presentation: chest pain in a patient with known cardiac disease might be investigated differently from chest pain occurring in a previously healthy individual. Misdiagnosis is likely to result in patients returning to the environments in which poisoning has occurred and is likely to continue to occur. If there is no intervention to stop exposure occurring, then the potential for continued exposure to impact on health so that it results in a death is possible, either by triggering or accelerating the progression of disease. CO exposure is currently only confirmed when suspicion that it may be playing a role is raised by the healthcare professional and action is taken to investigate.

Investigation by the healthcare professional would ordinarily begin with a blood test. Raised levels of COHb would indicate exposure to CO, as would blood pH values less than 7.20 in patients not exposed in fires (although COHb is specific to CO and pH value is not). Very high levels of COHb, pH levels less than 7.20 and loss of consciousness are characteristics of CO poisoning that would indicate poor prognosis for patient survival[17]. At non-lethal levels, a healthcare professional would need to undertake, depending on the clinical setting, the same blood tests or a breath test to measure exhaled CO, but interpretation of the results would need to be made in conjunction with other information either gathered via patient questioning or provided by an appliance engineer, paramedic, or fire and rescue personnel who might be able to confirm exposure through appliance testing, ambient monitoring, patient monitoring or in some cases, reporting of a CO alarm sounding in the environment where exposure occurred.

[17] Rose et al, 2017, Carbon monoxide poisoning: pathogenesis, management, and future directions of therapy. Am.J.Respir.Crit.Care.Med 2017;1;195(5):596-606.

It is important to note that standard pulse oximetry which monitors the saturation of the blood with oxygen is likely to be misleading in cases of CO poisoning because the method does not distinguish between oxyhaemoglobin and carboxyhaemoglobin. Measurement of the level of saturation of haemoglobin with carbon monoxide, by pulse CO oximetry, is obviously more valuable.

In addition, the accuracy and interpretation of the result of any test for CO is dependent on the time that has elapsed since exposure occurred. Measured, non-lethal levels of COHb do not give an indication of patient prognosis and do not indicate the maximum level of CO to which the patient was exposed, nor the duration of exposure.

Diagnosing CO in the deceased can be undertaken by measuring COHb in blood. COHb levels are not altered after breathing ceases and therefore provide a good indication of the level of CO in the body at the time of death. High levels of COHb will not be recorded on a death certificate as the cause of death itself, but will be coded for (as T58) if implicated as an underlying cause of the death. It is usual for this to apply in fatal acute exposure cases where pathology results indicate levels of COHb above those found in smokers or where CO has already been implicated as an underlying cause of death through other investigation routes. Scientific research is evolving and investigating other methods of measuring CO exposure: in particular, new biomarkers in the brain and blood are being developed[18]. If CO poisoning is suspected in the deceased, such cases are required, by law, to be referred to the Coroner for further investigation[19].

Therefore, in both live patients and in the deceased, if CO exposure is missed, not suspected or lower levels of COHb that are detected do not raise suspicion, there will be no official, quantifiable record of CO exposure made.

The scientific evidence

TOXICOLOGY

The usual route of exposure to CO is via inhalation. CO is inhaled into the lungs where it passes into the blood and combines with haemoglobin to form carboxyhaemoglobin. CO binds with deoxyhaemoglobin, the deoxygenised form of the protein haemoglobin in exactly the same way as oxygen but with ~240 times greater affinity. The binding of CO to haemoglobin reduces the uptake of oxygen and thus the transport of oxygen to the tissues of the body is impaired. The release of such oxygen as is bound to haemoglobin is also impaired. This produces a state of hypoxia (a lack of oxygen)[20]. The lack of oxygen impairs production of ATP the "energy currency" of cells. A reduction in the availability of ATP causes defects in cellular function and cell death. The generation of free radicals is increased and inflammation may be induced[21,22]. Cells of tissues with a high oxygen demand are particularly affected: those of the heart and central nervous system are amongst the first affected. The extent of the damage caused is, of course, dependent on the level of hypoxia and on how long it persists. Inhalation of exogenous CO is also known to increase endogenous CO production via the conversion of free haem by haem-oxygenase into bilverdin, iron and CO[23], thereby creating an addition to the availability of CO over and above that being inhaled. This would potentially have an important impact on those chronically exposed to CO and who were already medically compromised.

[18] Gas Safety Trust. Research Portal. www.gassafetytrust.org (accessed January 2020).

[19] Coroners and Justice Act 2009. www.legislation.gov.uk (accessed January 2020)

[20] Maynard R.L et al, Carbon monoxide. In Purser D, Maynard RL & Wakefield J (Eds.) Toxicology, Survival and Health Hazards of Combustion Products. Royal Society of Chemistry 2016.

[21] Ibid

[22] Rose et al, 2017, Carbon monoxide poisoning: pathogenesis, management, and future directions of therapy. Am.J.Respir.Crit.Care.Med 2017;1;195(5):596-606.

[23] Cronje F.J et al,. Carbon monoxide actuates O()-limited heme degradation in the rat brain. Free Radic. Biol. Med.2004;37(11):1802-1812.

CARDIOVASCULAR TOXICITY: IMPLICATIONS FOR LONG TERM MORTALITY

Figures from the British Heart Foundation indicate that more than a quarter of all deaths in the UK are caused by heart and circulatory diseases. This equates to nearly 170,000 deaths each year of which 44,000 occur in people under 75 yrs[24]. With around 7.4 million people living with heart and circulatory diseases in the UK[25], the impact of an attributable, but avoidable risk factor should not be disregarded. Healthcare costs for these conditions are estimated at £9 billion each year, with these costs rising to an estimated £19 billion each year as a cost to the UK economy when the cost of premature death, disability and informal costs are included[26]. The particulate matter component of ambient air pollution is estimated to be attributed to 11,000 heart and circulatory disease deaths in the UK[27].

Understanding the impact that CO has on cardiovascular toxicity and lifelong health and wellbeing, given the longer exposure times and element of uncertainty on safe gas use, especially in homes, is of public health importance.

The toxicological literature clearly shows that CO poisoning, particularly at moderate to severe levels of exposure, has effects on the cardiovascular system. Non-smoking patients with elevated levels of COHb may present at hospital with symptoms including chest pain[28] and diagnoses of myocardial injury, left ventricular damage, arrhythmias[29, 30, 31]. Kaya et al, 2016[32] reported an increased risk of acute myocardial infarctions associated with moderate to high levels of CO exposure in the long term. A number of mechanisms specific to poor cardiac outcome have been identified following exposure to CO. The best established mechanism involves damage to cardiac muscles cells by hypoxia and the induction of an inflammatory response. Hawkins[33] provides a clear account of this mechanism. The effects are many: including arrhythmia, cardiac hypertrophy, AMI, fibrosis, atherosclerosis, vasodilation and oedema. The effects of CO exposure on those already compromised by heart disease will likely include worsening of their condition. Other mechanisms include the direct action of CO on myoglobin, cytochromes and at other molecular binding sites[34].

[24] BHF. UK Factsheet 2020. www.bhf.org.uk (accessed February 2020).

[25] ibid

[26] ibid

[27] ibid

[28] Clarke S. et al,. Screening for carbon monoxide exposure in selected patient groups attending rural and urban emergency departments in England: a prospective observational study. 2012 BMJ Open2 e00087.

[29] Rose et al, 2017, Carbon monoxide poisoning: pathogenesis, management, and future directions of therapy. Am.J.Respir.Crit.Care.Med 2017;1;195(5):596-606.

[30] Henry C.R. et al., Myocardial injury and long-term mortality following moderate to severe carbon monoxide poisoning. 2006;295:398–402

[31] Satran D. et al., Cardiovascular manifestations of moderate to severe carbon monoxide poisoning. 2005;45:1513–1516.

[32] Kaya H. et al., COHgb levels predict the long-term development of acute myocardial infarction in CO poisoning. 2016;34:840–844

[33] Hawkins K, et al (pending publication)

[34] Maynard R.L et al, Carbon monoxide. In Purser D, Maynard RL & Wakefield J (Eds.) Toxicology, Survival and Health Hazards of Combustion Products. Royal Society of Chemistry 2016.

NEUROLOGICAL TOXICITY: IMPLICATIONS FOR LONG TERM MORTALITY

Individual case histories have provided awareness amongst healthcare professionals that neurological problems can develop as a result of CO exposure, both immediately and weeks after apparent recovery. In some cases, the effects are long lasting. The majority of problems described are those affecting memory, visual spatial function, executive function, problems with speech, language, reading and writing, attention and cognitive processing speed, co-ordination and fine motor control, fatiguability[35]. There are many hypotheses explaining why neurological injury occurs following exposure to CO and damage can be certainly be found in areas that are susceptible to hypoxic injury[36]. Non-hypoxic pathways that produce an injury cascade are also being explored where neurological injury is activated directly by CO toxicity. Here, CO toxicity triggers glutamate excitotoxicity, mitochondrial dysfunction, oxidative stress and inflammatory processes that result in an injury cascade resulting in brain cell death[37,38].

[35] All Party Parliamentary Group. Carbon monoxide poisoning: saving lives, advancing treatment. A call for action across the healthcare sector. COMED 2017. Policy Connect. www.policyconnect.org.uk.

[36] Meyer A. The selective vulnerability of the brain and its relation to psychiatric problems, Proc.Roy.Soc. Med., 1936, 29,1175-1181.

[37] Weaver L.K. Clinical Practice. Carbon monoxide poisoning. N.Engl.J.Med. 2009;360(12):1217-25.

[38] Piantadosi C.A. et al., Apoptosis and delayed neuronal damage after carbon monoxide poisoning in the rat. Exp.Neurol. 1997;147(1):103-14.

The risk of exposure to CO

PROBLEM APPLIANCES AND UNSAFE GAS WORK IN THE UK

According to the Gas Safe Register, nearly half of all households (46%) in the UK do not have a CO alarm. This equates to nearly 12 million households. Additionally, gas industry figures estimate that in 2016 there were 1.1 million jobs carried out by illegal gas fitters[39]. From an industry study of 5,000 homes using illegal gas fitters, 3 in 5 appliances were found to be unsafe and 1 in 3 were found to be immediately dangerous[40].

BEHAVIOUR CHANGE TO REDUCE RISK AND IMPROVE DATA COLLECTION

The All Party Parliamentary CO Group report 'Carbon monoxide: from awareness to action – bringing behavioural insights to poisoning prevention efforts'[41], clearly highlighted a number of behaviours that increased the risk of exposure to CO in different environments and situations. Understanding the behaviours that encourage an increase in risk of exposure can guide stakeholders in the design of interventions to prevent exposure. However, whilst the All Party Parliamentary CO Group report investigated ways of improving prevention strategies through community behaviour change, action by other CO stakeholders is now required. For example, in considering 'context' (the high level understanding of the environment where the intervention is to take place) is required. Understanding the environment in which diagnosis of CO exposure is likely to take place is key to understanding the barriers to making a correct diagnosis. In this case, the setting itself is important: this could range from a busy Emergency Department (ED), to a GP surgery to a midwife in her woman's home. From this knowledge further understanding is required: for example, the equipment at their disposal, patient records, the speed at which tests can be carried out and results returned, and referral options available to that professional. Once 'context' is fully understood, the 'intervention' can then be tailored to that specific healthcare professional's setting. The same consideration can be applied to other aspects of behaviour change. *'Providing information at the right time with the right approach can bring results'*[42].

Behavioural frameworks can be used across the range of CO stakeholder practices for improving diagnosis of CO, for prevention strategies and for the improvement of data collection. Behaviour change should be an important factor in the consideration of improved surveillance strategies for CO.

[39] www.gassaferegister.co.uk/news/news-2016/more-than-a-million-households-put-at-risk-by-illegal-gas-fitters

[40] ibid

[41] All Party Parliamentary CO Group. Carbon monoxide: from awareness to action – bringing behavioural insights to poisoning prevention efforts. 2015. Policy Connect

[42] ibid

Duties of healthcare professionals for the deceased

THE INTRODUCTION OF MEDICAL EXAMINERS

The recent reforms set out in the Coroners and Justice Act 2009, made a change in the legislation that permitted an independent Medical Examiner to scrutinise all deaths in England and Wales that are not investigated by the Coroner. The aims of the reforms were to improve the accuracy of death certification; make referrals to the Coroner more consistent and appropriate; eliminate Registrar rejection of the medical certificate cause of death and assure input from relatives[43].

Medical Examiners are senior doctors, specifically trained to scrutinse non-coronial deaths that occur in hospitals (although this is to be rolled out to include deaths in other NHS settings, independent settings and in the community within a specified geographical area). Medical Examiners are required to evaluate the cause of death proposed by the attending doctor using proportionate scrutiny of medical records, assessment of information provided during an interview with the next of kin, and through an external examination of the body[44]. Others responsible for the provision of healthcare for the deceased may also be questioned. This process requires the following of Good Practice Guidelines. The death will only be registered once agreed by the Medical Examiner, or by the Coroner (should a death be referred). In undertaking scrutiny of death certificates, Medical Examiners advise on the best wording to sufficiently explain the chain of causation resulting in the factor that caused death.

THE ROLE OF CORONERS IN CO DEATHS

The Coroner's principle responsibility is to establish a cause of death. This is determined by means of an investigation following the referral of a case from, for example a Medical Examiner or the police. Currently about 45% of deaths are referred to Coroner. These referrals occur either because the cause of death cannot be determined, or because the death falls into a category that requires referral by law.

The Coroner has wide discretion in setting the scope and breadth of an investigation[45]. The scope of an investigation is decided by the Coroner and it is the Coroner's duty and responsibility to ensure that the relevant facts are exposed to scrutiny[46]. Whilst each case is determined independently, evidence that can identify illegal conduct or neglect is sought. This is of particular relevance to exposure to CO where illegal conduct (particularly on the part of illegal (not registered) gas fitters, and neglect (perhaps unwittingly from those in positions of responsibility who are unaware of the dangers of CO) may arise.

Coroners will have a case referred to them if CO is suspected. CO is a poison and all cases of poisoning require referral to the Coroner.

Coroners are independent and report only to the Chief Coroner. Whilst Coroners are able to request an autopsy on the deceased, the Coroner must have reason to suspect that the results of an autopsy will reveal evidence to facilitate and ultimately establish a cause of death. This makes a specific, Coroner-wide, mandatory request for routine testing in all deaths for CO, unlikely to be accepted in England and Wales.

[43] Dept Health, 2016 reforming death certification: introducing scrutiny by Medical Examiners. Lessons from the pilots of the reforms set out in the Coroners and Justice Act 2009

[44] Dept Health, 2016 reforming death certification: introducing scrutiny by Medical Examiners. Lessons from the pilots of the reforms set out in the Coroners and Justice Act 2009

[45] Chief Coroner LAW SHEET No5 the discretion of the Coroner, January 2016.

[46] ibid

PATHOLOGY

Autopsies ordered by Coroners are performed by pathologists but can also be undertaken by any registered medical practitioner. Only tests that are likely to inform on the cause of death and manner of death are undertaken, and these are as minimally invasive as is consistent with the production of reliable results. For CO, interpretation of toxicological tests would be undertaken. Tests are individually costed.

Consultation on the initial evidence gathered

Consulting on the evidence so far gathered, understanding the recent changes to the system of referral and scrutiny, and harnessing thoughts on future plans to develop and implement new legislation, required a roundtable event. This event was held to facilitate the development of a strategy that would enable an holistic approach to data gathering to improve an understanding of mortality associated with exposure to CO. It was clear that *'mortality associated with CO'* had a number of variables associated with it, requiring the consideration of levels of exposure that would immediately cause death, levels of exposure that would trigger, accelerate or worsen disease to the point of death and the roles of different specialists who would be involved in confirming the of cause of death. Understanding how the development of scientific understanding of the effects of CO on health would impact on both the healthcare professionals' completion of a death certificate and on coronial investigations, was important.

THE DEVELOPING SCIENCE OF CO TOXICOLOGY: HARNESSING THE ROLE OF THE MEDICAL EXAMINER, PATHOLOGIST AND CORONER – ROUNDTABLE EVENT

A roundtable event was held between a small, multi-disciplinary group of scientific, healthcare and policy professionals to discuss the identification of CO in the cause of deaths, and the challenges and opportunities presented by the introduction of the Medical Examiner system. The event, *'The developing science of CO toxicology: harnessing the role of the Medical Examiner, pathologist and Coroner'*, chaired by Professor Baroness Finlay of Llandaff, was held on the 22nd July 2019 and was supported by Cranfield University and Gas Safety Trust as part of this research.

The event addressed two areas:

1) **the impact that the development of scientific evidence on CO exposure could have on the role of the Medical Examiner system:**
2) **the impact that the development of CO testing in pregnancy might have on coronial investigations and on the potential legislation of coronial investigations into stillbirths.**

The background to the event was described and an overview of the development of the scientific understanding of the effects of CO explained.

CO scientific development

A detailed evidence session on the basic science was delivered by Dr Robert Dickinson (Imperial College). This highlighted the implications of CO exposure for the cardiovascular and neurological systems, the damage that can be caused, the known and less understood mechanisms of effect and the consequences of exposure on later mortality including coronary heart disease, stroke and dementia. Dr Dickinson provided an overview of his work in an animal model that to date had considered neurological assessments of gait and memory following exposure to different CO exposure levels and patterns. Histopathological analysis had yet to be undertaken. Further study in animals was discussed in light of the second area addressed by the meeting: the effect of CO on the fetus and implications for development and unexplained stillbirths. It was noted that in vulnerable households, exposure to environmental CO from faulty and malfunctioning fuel-burning appliances, is more likely, as is the likelihood of exposure to CO from tobacco smoke. This had implications regarding the effects of exposure to CO on the pregnant women, on her developing child and on exposure during early childhood. It was noted that information of the effects of CO as a single pollutant was needed in order to interpret the effects of exposure to combinations of pollutants such as was inevitable in the case of indoor and outdoor environmental exposures, and exposures of tobacco smoke.

CO in pregnancy

Hilary Wareing (IPIP) then developed this area of discussion by delivering the second evidence session which considered the implications of exposure to CO for the pregnant woman, her unborn child and the neonate. It was highlighted that in adherence with best practice measures, exhaled CO was now being measured in all pregnant women. However, little is known of the impact that the levels of CO being measured in pregnant women have on the developing child, nor on the child's development long term should the CO exposure in the home continue. It was explained that for maternity services, the primary achievement is a live and healthy birth outcome for mother and baby followed by discharge from hospital. There is no home check to ensure that the baby will be living in a safe environment, although the community midwife conducts a visit(s) in the home during the first week after birth. Beyond two weeks post birth, regular healthcare checks are provided by a health visitor, these are more likely to take place in a community health centre than in the home. It was confirmed that CO exposure is not considered as an issue to be investigated in post-natal care. Whilst reflecting on the scientific evidence, although it was noted that a formal literature review had not recently been undertaken to provide comprehensive analysis that included the most recent literature, it was considered reasonable to uphold the conclusion that long term CO exposure either pre- or post-natal, should continue to be considered a causal factor in poor birth outcomes and developmental effects. Whilst the scientific evidence is suggestive of a causal relationship, further investigation would be required to confirm new information related to dose, exposure patterns and additive effects of CO from other sources. Improved testing, data collection and further toxicological study would provide important information on the impact of long term CO exposure on the development of organs, in particular the heart, and on the risk of fetal death, still births and poor birth and developmental outcomes. Currently, if a mother has smoked during pregnancy and the pregnancy results in a still birth, or if the baby is born with a birth defect or develops learning disabilities, healthcare professionals are quick to assume that smoking was the cause of these outcomes. Currently, 50% of stillbirths undergo post mortem examination.

DISCUSSION POINTS FROM EVIDENCE SESSIONS

Scientific development

- The difficulties associated with both diagnosis and follow-up of the CO poisoned patient were discussed. It was highlighted that a study of CO poisoned patients and common misdiagnoses, such as Myalgic Encephalomyelitis (ME) type syndromes, had not been undertaken. Whilst it was noted that large epidemiological studies on CO poisoning had not been undertaken, in a survey of people who had experienced CO poisoning, ME had been the most common misdiagnosis. Analysis of data on common misdiagnoses and diseases triggered or accelerated by CO poisoning should be undertaken in conjunction with the development of data collection on CO.
- The importance of data capture was acknowledged. It was questioned whether accessing Biobank data would be useful. The absence of a database system that could capture the currently fragmented data from different stakeholders was noted.

  Action: The utility of Biobank data should be considered.

  Action: Develop solutions to authenticated data capture on CO from multiple sources and ensure secure storage and access.

- Research on the effects of CO poisoning on cardiac and neurological damage needs to be further developed.
- Carboxyhaemoglobin is more problematic for the fetus and neonate than the mother.
  - Scientific research in this area in humans is difficult.

  Action: Research is required into the effects of CO on the fetus and neonate.

- There was discussion regarding the study of umbilical cord blood COHb vs that of the mother. This was certainly possible in animal research and could be carried out in pregnant animal models exposed for specified durations to specified levels of CO throughout pregnancy. It was acknowledged that data would be harder to obtain from pregnant women due to ethical constraints and the difficulties arising from obtaining maternal blood COHb, exhaled breath CO and the potential confounding that the provision of O2 during some births would have.

  Action: Research studying umbilical cord blood COHb vs maternal COHB in animal models should be taken forward.

- It was noted that research involving pregnant women had to be very carefully considered; developing research on CO that would be successful in obtaining ethical approval would have to consider the mental and physical vulnerability of the woman and her unborn child throughout and beyond the study itself.
- There was also discussion regarding umbilical cord blood analysis in cases of stillbirth. Raised COHb / whole CO (although research would be required on what would be considered raised levels) would result in an inquest, which would require a system to produce evidence-based answers and support for the grieving mother and wider family.

  Action: Urgent research is required on the levels of COHb in umbilical cord blood fetal blood to provide the evidence base for raising an inquest on a stillbirth [if applicable pending outcome of the consultation 2019].

- It was noted that similar evidence was required during discussion that related to sudden neonatal deaths.

  Action: Research was required to better understand the levels and durations of exposure to CO that could result in a neonatal death.

It was acknowledged that funding for research needs to be made available and a programme of research and innovation developed and supported to tackle CO.

EXPOSURE DURING PREGNANCY

A number of questions were posed:

- **Where was the data collected by midwives on CO levels in their women stored?**
  - Expired CO breath data recorded by midwives is available, but is not centrally stored, making analysis difficult;
  - Data collection on CO exposure in the population needs to be improved and centralised;
  - How many women who do not smoke have raised levels of CO in their breath as a consequence of environmental CO exposure at their first booking? This was not known.

  Action: It was agreed that the data stored by each NHS Trust should be accessed and analysed.

  Action: It was suggested that the RCM should be given access to the CO data on pregnant women long term.

- **What was the referral pathway for non-smoking women who tested positive to CO exposure?**
  - For women who had positive breath test readings, what advice were they given? What actions should they take?
  - What information was there available regarding endogenous levels of CO in pregnant women?

  Action: It was noted that a referral pathway was required to assist hospital midwives, community midwives and health visitors provide advice and direct women identified as potentially exposed to environmental CO to further services. It was noted that this referral pathway might not lie wholly within the health service.

- **It was noted that the use of HBOT as a treatment for CO exposure was no longer available for pregnant women;**
  - It was suggested that further research was required to provide scientific evidence to facilitate the provision of updated guidance on the treatment of CO exposure in pregnant women with a focus on best outcomes for the woman and her baby;
  - Basic research was suggested to investigate the use of HBOT vs O2 as a treatment for CO exposure in pregnant women throughout pregnancy, with a focus on fetal development and birth outcomes.

  Action: Further research to inform the update of treatment protocols for pregnant women exposed to CO was required.

  Action: Research to improve understanding of the impact exposure to CO has on the fetus at critical stages of development is needed.

- **The vulnerable status of pregnant women was raised.**
  - Pregnancy itself makes women vulnerable;
  - Women who are smokers are more likely to be additionally vulnerable: living in poor housing and therefore at higher risk of CO exposure in the home.
  - Pregnant women living in poor housing are also likely to be in fuel poverty, although less likely to be signed up to any government or industry scheme that offers financial aid.

  Action: Understanding why additional vulnerability associated with pregnancy and CO is not adequately addressed by government and industry needs to be investigated.

It was agreed that CO exposure in-utero and by the neonate was an area that required urgent funding to provide evidence for healthcare, industry and stakeholder solutions and interventions.

THE MEDICAL EXAMINER SYSTEM

Dr Alan Fletcher (NHS National Medical Examiner) provided an overview of the Medical Examiner system, noting that at the time of the round-table, it was still in its non-statutory phase. Currently, the work was in the non-acute hospital phase, with an expected roll out to the acute hospital phase, and then in the consideration of deaths in the community. Medical examiners were expected to refer cases to the Coroner if there was reasonable evidence to suspect that there was poisoning. This would include poisoning by CO. Once a case had been referred, the Medical Examiner's involvement would end. Dr Fletcher explained that CO poisoning would therefore not be recorded as a cause of death on a death certificate by a Medical Examiner as CO poisoning would be considered an unnatural death and therefore one that required referral to a Coroner. It was noted that the Medical Examiner does not carry out a forensic medical assessment of the deceased.

Discussion: Medical Examiners, Coroners and CO

The discussion of the role of the Medical Examiner was considered in the hospital setting and in the community setting, noting that Medical Examiners were not as yet serving in the latter.

In both the hospital and community setting, it was clear that Medical Examiners would not confirm a death from CO poisoning as a suspected death from CO would need to be referred to the Coroner. It was therefore noted that it was important for Medical Examiners to be reminded of clues that might raise suspicion of exposure to CO being an underlying cause or contributory factor of death so that occurrences that required referral to a Coroner would not be missed.

It was considered unlikely that a patient would die in hospital from an exposure to CO that had been emitted from within the hospital. However, the patient who had been admitted, unconscious, from the community setting could have been exposed to a level of CO that prevented them from regaining consciousness. Such a scenario should result in a coronial investigation, but would require suspicion of poisoning having occurred.

Discussion of a death occurring in the community setting highlighted that the Medical Examiner would need to be alert to the possibility that the deceased could have been poisoned by CO. A high exposure causing death would require referral to the Coroner for further investigation.

All deaths involving any form of poisoning must be referred to the Coroner. The key was for the Medical Examiner to be suspicious that CO might be implicated.

The discussion continued and became more complex when considering deaths where lower levels of CO and the implications of exposure for the deceased could have been an important contributor to death. In part, the difficulties raised in the discussion revolved around the many different scenarios in which poisoning could occur, the effects of CO exposure at different stages of the life-course with a particular emphasis on co-morbidities, vulnerabilities and behaviours; the effects of different exposure levels, durations and repeated exposure.

It is a statutory requirement that any death involving poisoning by any substance has to be referred to the Coroner. In the consideration of situations where chronic exposure to lower levels of CO might be implicated, it was thought that a Medical Examiner would only be likely to consider lower levels of CO whilst considering Part 1b, c or Part II of the death certificate. It was most likely that at this point, the case would be referred to the Coroner. However, questions were raised as to:

1) **What information would be required to prompt and facilitate the consideration of lower levels of CO exposure as an underlying cause or important contributor to a death;**
2) **what level of suspicion or evidence would be required to instigate a referral to the Coroner?**

The role of the Medical Examiner to scrutinise (but not complete) certificates was reinforced. For deaths occurring in the hospital setting it was considered unlikely that acute high level exposures of CO poisoning would be missed. However, there was suspicion that not all cases that resulted in death in hospital would necessarily be identified as being CO related. Irrespective of access to information that provided confirmation of exposure with an indication of dose or time-frame associated with exposure, the cause of death would still be the medical condition that caused the death event. The referral to the Coroner would be made following suspicion that a coding for CO as the underlying cause of death was required, resulting in further investigation involving, for example HSE under RIDDOR.

However, if there was no information that raised suspicion of CO accompanying the admission of the patient and the patient's medical history or the nature of the death was not unusual, then in such cases CO exposure would be missed. This resurrected the discussion on the need for heightened awareness in healthcare professionals to rule out CO.

It was noted that a measure of COHb should be listed as part of a routine test when blood is drawn on a patient on arrival at ED, despite the potential for confounding in smokers. This would in the first instance assist in the scrutiny of death certificates relating to CO exposure. Whilst measurement of COHb would prompt the consideration of CO exposure, the interpretation of the result would be key (as well as acknowledging the result amongst other blood measurements), particularly in a patient who had smoked, or who had been provided with oxygen. Work was needed to establish an improved understanding of the results of COHb levels and to develop new biomarkers to assist with distinguishing between exposure to different sources of CO. Such clues (other than 'cherry red' skin) would need to be considered to facilitate an appropriate referral to a Coroner, remembering that the Medical Examiner does not order or perform any toxicological investigations. The point was raised that generally, COHb was measured more routinely in France.

How this would translate to the identification by the Medical Examiner of lower levels of exposure was less clear. This was more likely to be of importance in the case of a subject who had had an underlying health condition where chronic lower levels of exposure had accelerated or worsened the condition to the point where death was brought forward. Two points were raised:

1) **whether this was an area where specialists needed to be engaged regarding the effects that CO could have on their patients?**

It was suggested that there was scope for informing specialist healthcare professionals as to the effects CO could have on their patients and that this should be considered as part of a training and awareness programme for healthcare professionals.

2) **The Medical Examiner has the authority to question the relatives of the deceased, a process that might establish if there was the potential for exposure of others to the source to which the deceased had been exposed. It was noted that this would also protect current occupants at that address from exposure.**

This was considered an important capability of the Medical Examiner. However, the sort of questions asked would need to be considered: 'do you have a CO alarm?' on its own might not be sensitive enough to pick up issues of lower level exposures that do not trigger an alarm sounding. Whilst a short battery of questions might reveal clues, it was not necessarily considered appropriate as the focus of such discussion with the family would be to address concerns that they, the family, might have. However, it would also be important for the Medical Examiner to pick up clues that might raise suspicion from general discussion with the family. These clues could be wide ranging and would require a broad appreciation of CO: an appreciation that could be acquired through training and workshops. It was noted that low levels of exposure to CO that might still have played an important part in an individual's death would be less likely to be identified.

The group was reminded that the Medical Examiner's investigation is not a thorough forensic investigation, and that their remit was to look for a cause of death, and comply with the regulations for referral to Coroners.

Discussion: pregnancy, stillbirths coronial investigations & CO

It was immediately understood that this discussion was very sensitive. It was explained that the Child Death Review procedures were to be implemented to understand why children die and it was noted that there was a National Child Mortality Database which acted as a repository for all data relating to child deaths. This was upheld as a route for learning how to reduce child deaths. The Medical Examiner's responsibility is to ensure that, as with adults, the cause of death is accurately recorded by the attending practitioner on the Medical Certificate of Cause of Death (MCCD) and that if required, a timely and appropriate referral to the Coroner is made; and possible clinical governance concerns have been highlighted. The Medical Examiner is also able to discuss these concerns with the family. This would apply to a person under the age of 18yrs. It was noted that implementation was expected in September 2019.

The applicability of new coronial powers to investigate stillbirths was discussed given the consultation on this government proposal in March 2019.

It was noted that the scientific literature showed younger children had a heightened vulnerability based on their higher respiration rate. But also that there was a heightened risk related to exposure *in utero*. This latter point was expanded on within the discussion: that in utero exposure and thus the unborn child was not considered a vulnerable group by industry was agreed to be an oversight. What was clearly a failing was that whilst pregnant women were being monitored for exposure to CO, whether from smoking or environmental exposure, it was difficult to leverage any action for environmental exposure to CO because of this lack of vulnerable status by industry. It was understood that part of the problem was that managing this vulnerable group would be difficult, particularly given that with pregnancy putting women into a vulnerable position anyway, the most vulnerable pregnant women were those who were most likely to be exposed to CO.

There is a paucity of studies of fetal exposure to CO. However, there is sufficient evidence to class CO as a teratogen and for work from the smoking in pregnancy literature to provide direction to develop the evidence base on the effects of CO on the developing fetus. Pregnant women are more likely to be exposed to CO for longer durations due to the amount of time spent indoors. They are also more likely to ignore the symptoms of CO exposure that mimic those of pregnancy. If they are in poverty driven situations giving rise to the use of poorly maintained appliances, CO exposure is a real risk that has been witnessed and highlighted in midwife case studies.

The discussion of coronial investigations into stillbirths at term and how this might assist with deaths that involved exposure to CO was taken forward. It was noted that the aim of stillbirth investigation was predominantly to improve maternity services. However, it also served to answer questions parents may have relating to the death of their child and prevent further deaths, particularly during labour or birth. The group was reminded that the role of the Coroner was to identify cause of death. It was questioned whether the intrusive and emotive investigation of a stillbirth by the Coroner at full term would add sufficiently to an understanding of the underlying cause of death due to environmental CO exposure *in utero*. It was noted that perhaps further scientific research was required on this area before considering coronial investigation of stillbirths.

However, the investigation of child death will be of immediate importance for the identification of CO exposure, particularly at the neonatal stage where the home environment is key to a healthy start in life. In utero exposure followed by post-natal exposure needs to be further investigated as currently the scientific evidence points towards this continuation of exposure outside of the womb to play a part in health and developmental problems.

The Prevention of Future Deaths report was mentioned as a way for Coroners to stimulate action to prevent future deaths. By requiring the recipients of these reports to respond, the Coroner can leverage action for improvement. The repeated call for action on any theme should raise the alarm that there is a lack of action or that actions currently being taken are failing. The short discussion on databases confirmed that whilst a Medical Examiner database was being developed by the Department for Health and Social Care (DHSC), when contacted it was explained that they were not currently able to share information as the database was still under development. It was noted that the Chief Coroner produces an annual report on deaths from submissions from Coroners, but it was noted that there was not currently a sophisticated system for sharing findings.

Other points raised:

- **It was noted that coronary service and the human tissue act are unified but the post-death reviews is within the NHS so it is separate;**
- **It was noted also that the effects of CO can be masked by conditions such as stroke;**
- **Involving stakeholder industries to assist with confirmation of lower level CO exposure for healthcare professionals would be key.**

Actions arising out of discussion:

1. **It was advised that once sufficient progress had been made on the topic, that the Death Investigation Group at the RCPath should be contacted for further input and discussion of improving guidelines on autopsy practice to highlight CO and organising joint training initiatives.**
2. **It was advised that proposals should continue to be discussed with the Coroner's Office as work in this area progressed.**
3. **The group should consider how best to use different existing databases such as those from NHS Trusts and NHS Digital and BioBank for further study of the impact of CO on deaths.**
4. **Whilst steps are being taken to raise awareness of low level carbon monoxide monitoring, both among health professionals and in industry/utilities, analysis of data captured on CO needs to improve.**
5. **Resuscitation practices and how these affect the reliability of Coroner's examinations should be considered.**
6. **The role of district nurses and home care providers in inquiring about potential CO poisoning in the homes of their patients should be developed.**

Developing a reporting system

INTRODUCTION

Following the roundtable discussion, it was clear that contextual consideration of the different legislation and regulations that are also in place to prevent CO exposure occurring, was required. There are a number of government bodies and agencies whose remit in part, covers prevention of exposure to CO.

RESPONSIBILITY OF GOVERNMENT BODIES & AGENCIES

Government responsibility

As a direct response to the fact that death from accidental CO poisoning is in the majority of cases, avoidable, UK government departments and their agencies that had any remit that directly or indirectly had an impact on reducing the number of recorded deaths from CO (and in parallel, could undertake activities to reduce the number of exposures), formed a cross government group to tackle the issue.

The Cross Government Group on Gas Safety and Carbon Monoxide (CO) Awareness

This group was established to ensure a joined–up approach across departments, the devolved administrations and other governmental bodies. The Group's remit is to improve gas safety and reduce exposure to CO by promoting knowledge and understanding and facilitating the prevention and management of exposure to CO from all fuels. The Group's current membership is as follows:

- Department for Business, Energy & Industrial Strategy (BEIS)
- Department for Levelling Up Housing and Communities (DLUHC)
- Department of Culture, Media and Sport (DCMS)
- Department of Health and Social Care (DHSC)
- Health and Safety Executive (HSE)
- Health and Safety Executive for Northern Ireland (HSENI)
- Health Protection Scotland (HPS)
- Home Office
- Office of Gas and Electricity Markets (Ofgem) §
- UK Health Security Agency (UKHSA)
- Scottish Government
- Welsh Government
- Public Health Wales (PHW)

The Group reports on the work they have undertaken to fulfil their aim in the areas of consumer awareness, supporting professionals, research, legislation and securing justice, details of which can be found in their annual report[47].

[47] Cross Government Group on Gas Safety and CO Awareness, Annual Report 2017/2018, Published March 2019. https://www.hse.gov.uk/gas/domestic/cross-government-group.htm

Members of the Cross-Government Group on Gas Safety and CO Awareness

Below the roles of some of the members of the Cross-Government Group on Gas Safety Awareness that have not been referred to in other sections of the report are provided. This is done to help in the understanding of the remits held by these members and to assist in the development and consideration of recommendations that will be made. *It should be noted that UKHSA's role is discussed in the section on surveillance (p.44).*

OFGEM

Ofgem is a non-ministerial, independent regulatory authority, responsible for licenced gas supply and network operator companies to comply with their licence conditions. Ofgem is therefore able to place a number of obligations on gas retailers to protect their customers. For CO, the licence conditions require gas supply companies to provide their customers with information on:

- the safe use of gas appliances and other gas fittings;
- the dangers of CO poisoning;
- the benefits of fitting a suitable CO alarm that complies with a relevant British or European safety standard;
- the benefits of gas safety checks
- where to seek advice if gas appliances are condemned as a result of a gas safety check[48].
- And to protect vulnerable customers.

Ofgem seeks to encourage licensed gas supply and network operator companies to increase consumer awareness of the dangers of gas and the use of gas and has a number of mechanisms in place to achieve this[49]. Ofgem also operates the Gas Discretionary Reward Scheme (DRS) under the RIIO-GD1 regulatory framework that encourages gas distribution network companies (GDNs) to help address a range of social, CO safety, and environmental issues. Another initiative that relates to CO is the Fuel-Poor Network Extension Scheme: those in fuel poverty are known to be at greater risk of CO exposure[50].

Analysis and evaluation of information gathered from the outputs of these licence conditions and schemes are used to improve knowledge on the protection of public health from CO.

Another initiative launched in 2020 to support consumers in vulnerable situations and to address CO safety issues through collaborative projects that involve the Gas Distribution Networks, is the Gas Network Vulnerability and Carbon Monoxide Allowance (VMCA).

OFGEM also places obligations on gas retailers to adhere to the Priority Services Register, a mechanism that facilitates free safety checks of gas appliances to low income owner-occupants and vulnerable customers that are registered under the Priority Services Register (PSR).

[48] Standard conditions of gas supply licence Gas Act 1986 https://epr.ofgem.gov.uk

[49] ibid

[50] OFGEM. OFGEM confirms network price control methodology so consumers can benefit from cheaper, smarter and more sustainable energy network. www.ofgem.gov.uk

HSE

HSE is a ministerial government department that regulates domestic gas and works to secure justice and provide consumer protection where gas safety incidents are highlighted[51]. It aims to prevent injury and ill health in the domestic gas safety sector through the development of regulations, producing research and statistics, and enforcing the law. HSE has the powers to issue enforcement notices or prosecutions where the law has been breached under the Gas Safety (Installation and Use) Regulations 1998[52, 53].

In 2019, a memorandum of understanding was produced between the HSE and The Chief Coroner of England and Wales to promote and continue effective working. This was written taking into consideration the role of the HSE in enforcing the Health and Safety at Work Act 1974 and the assistance that HSE could legitimately provide to the Coroner following a work-related death.

Given HSE's role in regulating domestic gas safety, and that the HSE already work with Coroners when investigating deaths where lethal levels of CO are implicated as an underlying cause of death, the basis for similar co-operation being developed in relation to levels of CO exposure that triggers a death event or accelerates the cascade of events that result in death, would be recommended.

GSR

Gas Safe Register is only official gas registration body of gas businesses and engineers in the United Kingdom, Isle of Man and Guernsey. It supports enforcement activity through incident investigation, operational support and reporting to HSE; they undertake visits with HSE, local authorities; and complete inspections to identify unsafe gas work and assess engineers' competence[54]. Through its work, GSR maintains public health by facilitating the safe use of gas and by raising levels of awareness, knowledge and capability to prevent exposure to CO.

By law, all gas businesses must be on the Gas Safe Register.

DLUHC

DLUHC carries responsibility for producing the Building Regulations in England. There are many 'parts' to the Building Regulations and these cover different elements of the built environment that impact on CO exposure. The subject of Parts relevant to CO include ventilation, combustion appliances, conservation of fuel and power.

DLUHC carries responsibility for producing the Building Regulations in England. There are many 'parts' to the Building Regulations and these cover different elements of the built environment that impact on CO exposure. The subjects of Parts relevant to CO include ventilation, combustion appliances, conservation of fuel and power.

[51] Cross Government Group on Gas Safety and CO Awareness, Annual Report 2017/2018, Published March 2019. https://www.hse.gov.uk/gas/domestic/cross-government-group.htm

[52] HSE Public Record of Convictions www.hse.gov.uk

[53] HSE Media Centre http://press.hse.gov.uk

[54] GSR www.gassaferegister.co.uk

Alarm regulation

The provision of the regulatory requirements for CO alarms in homes forms part of the Smoke and Carbon Monoxide Alarm (England) Regulations.

On 30 April 2018, the Government announced a review of CO alarm requirements. The aim of this review was to consider and update the evidence base to establish whether the current alarm requirements in England should be extended from solid fuel appliances in private rental of residential premises to homes regardless of type of tenure[55]. Following consultation, the outcome of the review announced in November 2021 requires CO alarms to be fitted in rented and new build accommodation where there is a fixed combustion appliance, excluding gas cookers. This extended the current guidelines and obliged private and social sector landlords to repair and replace CO alarms[56].

CO alarms will sound if CO reaches levels that are considered to be of immediate harm to health. On sounding, occupants are expected to take immediate action to safeguard themselves and others in the property. Alarms are recognised as a line of defence against accidental, high level exposures to CO, but their installation should not be regarded as a substitute for the regular maintenance of carbon fuelled appliances.

Local housing authorities have the power to ensure that the Regulations are being followed and complied with.

Homes (Fitness for Human Habitation) Act 2018

Knowing that CO exposure occurs more frequently in the home, the Homes (Fitness for Human Habitation Act) 2018[57] that came into force in March 2019, lists CO as a pollutant of concern. Exposure to CO makes a home not fit for human habitation under the list of hazards set out in Schedule 1, with the caveat that the landlord will not be liable where:

1) **The problem is caused by the behaviour of the tenant;**

2) **the problem is caused by the tenants own possessions.**

The private rented sector is the second largest tenure in England, housing 4.7 million households (20% of all households)[58]. The Act provides the means to take irresponsible landlords to court, whilst protecting the tenant and provides a separate avenue for prosecution if gas appliances are not maintained according to gas safety regulations.

Green Paper: A New Deal for Social Housing

In August 2018, the Government published its Green Paper: A New Deal for Social Housing[59] to seek views on whether the Decent Homes Standard sufficiently covered issues relating to safety measures in social housing. This covered issues pertaining to CO exposure.

All Party Parliamentary CO Group

An All Party Parliamentary CO Group was established (originally the All Party Parliamentary Group on Gas Safety) with a number of specialised sub-groups comprising separately of representatives from CO stakeholder industries, charities, healthcare professionals, and specialists in science and technology; travel; and communications industry, to provide forums for discussion and facilitate understanding. The sub-groups inform cross-party Parliamentarians on specific issues pertaining to the prevention of CO that have policy relevance[60].

[55] Review of the smoke and carbon monoxide alarm (England) regulations 2018 www.assets.publishing.service.gov.uk

[56] Consultation outcome 2021 Domestic smoke and carbon monoxide alarms - GOV.UK (www.gov.uk)

[57] Homes (Fitness for Human Habitation Act) 2018. www.legislation.gov.uk

[58] English Housing Survey 2016 to 2017: headline report

[59] A new deal for social housing 2018 www.gov.uk/government/news/social-housing-green-paper-a-new-deal-for-socialhousing

[60] See: www.policyconnect.org.uk

Research and Development

The underpinning evidence to consider improved reporting of mortality data related to CO exposure was born out of the development of the basic scientific evidence predominantly over the past 10 to 15 years, but is not limited to this time period. This has suggested that longer durations of exposure to lower levels of CO have adverse effects on health, and being an important factor in death long term. Identification of CO in the ambient indoor air has also developed with improved sensor technology. Appliances and their flueing systems have also improved. New equipment has also assisted in the diagnosis of patients exposed to CO, by providing a non-invasive indication of whether or not a patient has been exposed. However, despite this research, CO remains a problem gas, with an unknown prevalence of effects on health in the UK.

The CO Research Trust (CORT) (formerly Gas Safety Trust) has provided funding for key pieces of research that are assisting the understanding of the prevalence and impact of CO on public health. The development of scientific understanding regarding CO has been augmented through the use of new, but well understood analytical methods and scientific practices that have not been used in previous investigations of CO. Improved understanding of the mechanisms of CO will facilitate the development of treatments and diagnostic biomarkers. The increase in knowledge will also help with the implementation of consensus and patient pathways. An improvement in diagnosis will assist with reporting and the improvement of data collection so that effective outputs from surveillance can be actioned. Access to funded research, workshop reports and papers can be found on their CO Portal: **www.coresearchtrust.org**

CO Charities

CO charities work to prevent CO poisoning, support victims of poisoning and their families and improve awareness[61, 62, 63]. Their work with the bereaved highlights the importance of improving the recording of deaths where CO is implicated. CO is a preventable non-communicable risk, making the majority of fatalities associated with accidental poisoning particularly harrowing. Whilst there is a call for improving the collection and analysis of data, it should not be forgotten that real people and real tragedies lie behind the numbers. Whilst the number of fatalities from acute high level poisoning is on a downward trend, there is uncertainty about the recorded figures based on the number of death certificates where CO is only mentioned in the narrative, and in cases where CO was missed and a referral to the Coroner not made. The figures that reflect death in the long term from chronic exposure to lower levels of CO, in conjunction with an underlying health condition is unknown. Their call for the requirement of improved data, their contribution to data collection, awareness initiatives and training is important.

[61] The Carbon Monoxide and Gas Safety Society www.co-gassafety.co.uk

[62] Katie Haines Memorial Trust www.katiehaines.com

[63] Gas Safe Charity www.gassafecharity.org.uk

Regulatory and Legislative changes to the investigation and reporting of deaths

REFORMS TO THE DEATH CERTIFICATION PROCESS

NHS England and NHS Improvement, DHSC, the Welsh Government and NHS Wales Shared Services Partnership are implementing the non-statute Medical Examiner system. A pilot scheme has been rolled out that covers non-coronial deaths occurring in hospital. However, over the course of 2020/2021, it is expected to be expanded to cover all non-coronial deaths (including deaths in the community) and eventually, the Medical Examiner system will be enshrined in statute. The aims of the reforms are to improve the accuracy of death certification; make referrals to the Coroner more consistent and appropriate; eliminate Registrar rejection of the medical certificate cause of death and assure input from relatives[64].

NOTIFYING DEATHS TO THE CORONER

In October 2019, new Regulations came into force that defined the range of circumstances in which deaths had to be notified to the Coroner.

There are three circumstances listed that could be applicable to CO in the Regulations, where the medical practitioner is required to consider whether:

'there is reasonable cause to suspect that the death was due to (that is, more than minimally, negligibly or trivially) caused or contributed to by the following circumstances.' [65]

These are:

- **Poisoning** – whether deliberate or accidental, including substances which would normally be benign but can be harmful at certain levels;
    - This would apply to accidental poisoning by CO at acute high (lethal) levels of exposure;
- **Exposure to toxic substances**
    - This would apply to accidental poisoning by CO;
- **Neglect, including self neglect where:**
    - Neglect in this context applies to the neglect of the deceased if they were in a dependent position (e.g. child, elderly, disability or serious illness) and there was a failure, omission or delay in the provision of basic and obvious requirements to the deceased. Examples provided include: adequate…warmth, medical assessment (these examples are discussed below).
    - However, also included is where a death, although from natural causes, it would be reasonable to suspect that the death resulted from 'some human failure, including any acts/omissions'.
    - Another context for neglect is applied where the death is due to the natural progression of an underlying illness, but where death was accelerated due to neglect by others[66].

[64] Dept Health, 2016 reforming death certification: introducing scrutiny by Medical Examiners. Lessons from the pilots of the reforms set out in the Coroners and Justice Act 2009

[65] Chief Coroner. Guidance No.31 Death Referrals And Medical Examiners September 2019 www.judiciary.uk

[66] Coroners and Justice Act 2009. www.legislation.gov.uk (accessed January 2020)

The combination of the categories 'Exposure to toxic substances' and 'neglect' are considered below in relation to CO exposure.

Exposure to toxic substances

CO is a toxic gas. The developing scientific evidence shows that even at lower levels of exposure, CO is able to trigger or contribute to a lethal event. The WHO, in their most recent guidance on exposure to CO, provide a 24hr averaging exposure limit of 6ppm, thereby indicating that exposure to this lower level of CO over a longer period of time, are considered toxic and harmful to health[67], in particular causing damage to the neurological system.

Neglect

Where the deceased is in a dependent position, neglect comes into force if anyone's failure to protect the deceased has contributed to the death[68]. In this instance 'anyone' can include family members, attending healthcare professionals, community healthcare professionals and care providers. There are a number of scenarios that could implicate a case of neglect where CO is concerned. Examples of neglect could be related to:

- not taking or taking inappropriate action or ignorance of the need for action related to:
  - a CO alarm sounding (battery replacement or CO exposure),
  - inappropriate appliance use by the occupant,
  - unintentional inappropriate appliance use by the care giver (e.g using the oven to provide additional heating, perhaps at the request of the occupant; using an old un-serviced portable appliance for additional heating),
  - reduced ventilation practices,
  - signs of CO production such as yellow flames from gas fires or stoves, sooty stains, smell of smoke, onset of condensation indicating poor ventilation.

The final context where neglect can be applied relates directly to the consideration of low to moderate levels of CO exposure:

'where the death of the dependent occupant is due to the natural progression of an underlying illness, but where death was accelerated due to neglect by others',

The examples of neglect again could be where intentional or unintentional action or lack of action falls under the examples given in the bullet points above, but that specifically contribute to for example:

- faster than expected increase of dementia symptoms wrongly attributed to "natural" worsening of disease.

This warrants further discussion and clarification, but serves to highlight the importance of awareness and training, in particular healthcare professionals and care workers attending patients in the community.

[67] WHO Guidelines for indoor air quality: selected pollutants. World Health Organization. Regional Office for Europe 2010. www.euro.who.int

[68] Chief Coroner. Guidance No.31 Death Referrals And Medical Examiners September 2019 www.judiciary.uk

Provision of adequate warmth: CO and Cold Homes

It is well reported that there is a significant likelihood of exposure to CO if a home is in fuel poverty and/or the home is not adequately heated[69, 70]. Cold housing is known to cause and contribute to excess winter deaths[71]. In 2014/15, the number of excess winter deaths attributed to cold housing was greater than mortality associated with road traffic accidents, alcohol or drug abuse[72]. However, there are other factors that contribute to cold homes and exposure to CO. Households that have a combination of financial, structural, health and age vulnerabilities are more at risk of exposure to CO and cold home vulnerabilities. These factors also contribute to behavioural practices associated with fuel burning, heating use, and the use of cooking appliances that increase the risk of exposure to CO. National Energy Action research has shown that cold homes are not likely to have a CO alarm and that occupants are more likely to use old and unsafe appliances intended for supplemental heating as their main heating source[73].

Table. 1:

Drivers, Pressures and Behaviours Associated with Cold Homes and CO Risk

Preventable mortality	Preventable mortality	Preventable mortality
Low income	Cannot replace inefficient boiler; Rationing heating;	Extended running periods of supplemental (older and not maintained) heating appliances
Lack of agency amongst tenants	Use of supplemental heating as cannot use central heating;	
Susceptible to the cold	To achieve adequate warmth requires the use of supplemental heating	

Adapted from NEA[74]

It is important that data on cold homes, vulnerabilities and death are included in the analysis of CO data to improve the outputs of surveillance and inform on interventions.

[69] UK Green Building Council. Health and Wellbeing in UK Homes. July 2016

[70] National Energy Action: Understanding carbon monoxide risk in households vulnerable to fuel poverty report 2017

[71] NICE. Preventing excess winter deaths and illness associated with cold homes. Quality Standard [QS117] March 2016 www.nice.org.uk

[72] UK Association for the Conservation for Energy. Chilled to Death: The human cost of cold homes. March 2015

[73] National Energy Action. Understanding Carbon Monoxide Risk in Households Vulnerable to Fuel Poverty. 2017

[74] ibid

Medical Assessment

Healthcare professionals can unwittingly send their patients home to a potentially lethal environment. Community healthcare workers, carers and homecare workers are also at risk of working in an environment where their patient or service user is continually exposed to CO. CO exposure, if it does not immediately cause death, can have effects on the neurological system with symptoms that mimic the expected or accelerated decline in memory, cognitive function and behaviours, more often associated with dementia and other neurodegenerative diseases[75]. Being dependent is a sign of vulnerability. Patients and service users with neurological or cardiovascular risk are at particular risk and a patient's or care user's condition can deteriorate and death brought forward without CO being identified as the cause of that deterioration or trigger of a fatal event.

It is therefore important that such homes not only have CO alarms or monitors that capture lower levels of CO that can alert the healthcare worker or homecare worker, but also that awareness of CO is high amongst professionals and the organisations that provide homecare services. Increasing professional awareness and knowledge to protect service users, vulnerable patients and careworkers from the dangers of CO is important not least because lack of awareness could result in deaths being referred to the Coroner as cases of neglect.

[75] All Party Parliamentary Group. Carbon monoxide poisoning: saving lives, advancing treatment. A call for action across the healthcare sector. COMED 2017. Policy Connect. www.policyconnect.org.uk

Identification of CO in the deceased

It is widely acknowledged that an improvement in the accuracy of certification of causes of death is required[76, 77, 78]. However, in the case of CO exposure there are many factors that require consideration.

Medical records might reveal that whilst the patient was alive, COHb had been measured. Results would indicate whether the patient had or had not been exposed, recently, to CO. However, interpretation of these results along with careful questioning would be required to raise suspicion of exposure to environmental sources of CO. On seeing the results, consideration would have to be made regarding:

- The place where the test took place;
- The time taken between the last potential exposure and the test;
- Where the exposure might have taken place;
- The duration of exposure;
- The possible maximum level of exposure (if not provided);
- How the exposure might affect the patient based on:
    - Estimated dose
    - Age
    - Co-morbidities
    - Pregnancy
    - Medication
    - Medical history (e.g. had the patient historically reported symptoms of CO exposure).

COHb does not provide an indication of patient outcome (prognosis) and further investigation would be required to ascertain whether the now deceased's previous exposure to CO was an underlying cause in the cascade of events that resulted in death or whether the exposure was a contributor to death, implicated in the chain of events that accelerated the progression of an illness or co-morbidity that itself was an underlying cause of or contributor to death.

In the deceased, the identification of CO exposure has traditionally been via assessment of %COHb levels found in blood using traditional spectrophometric methods. In the forensic setting, the accuracy of %COHb that can be determined by a conventional spectrophotometer has traditionally been considered adequate for purpose. The necessary equipment is widely available in analytical laboratories.

Traditionally, the results of tests for %COHb in postmortem blood would need to be high to confirm CO poisoning as an underlying cause of death. Lower, but still raised %COHb could be attributed to tobacco smoking, or death in the early stages of a fire. A development in the scientific understanding of the effects of lower level exposure to CO on the cardiovascular and neurological systems, has meant that the identification and consideration of CO at postmortem at lower %COHB than has historically been considered necessary, is now important.

[76] Slater DN. Certifying the cause of death: an audit of wording inaccuracies. J Clin Pathol. 1993; 46(3):232-4

[77] Morton L, et al. Incomplete and inaccurate death certification--the impact on research. J Public Health Med. 2000; 22(2):133-7

[78] Swift B& West K. Death certification: an audit of practice entering the 21st century. J Clin Pathol. 2002; 55(4):275-9

This development in the scientific evidence has raised concerns regarding the drawbacks associated with using COHb as a biomarker for CO exposure in postmortem blood. Traditionally, an error of +/- 10% in %COHb results has not affected interpretation. However, research has been undertaken that suggests that when considering lower levels of %COHb in post mortem blood, for example if the deceased was chronically exposed, an error of +/- 10% in the results could erroneously negate the level of suspicion raised in determining whether CO was an underlying cause in the chain of events that resulted in death. Such factors associated with causing this 10% error during the analysis of postmortem blood include: degradation of the blood sample during storage, thermo-coagulation, contamination from incomplete haemolysis, high lipid concentrations or thrombocytosis and putrefraction[79]. These factors interfere with the capacity of the spectrophotometer to provide a reliably accurate %COHb in post mortem blood at the level of precision that is required in the assessment of lower %COHb.

Another factor that requires consideration is the lower %COHb that might be significant in the death of older people or neonates (who still retain fetal haemoglobin in their blood for many weeks after birth). Patients with co-morbidities of the cardiovascular or respiratory system are also at risk when %COHb may appear low enough not to raise suspicion. In addition to disease, any separate toxic state can have additive effects (e.g., hypnotic drugs or alcohol). It is therefore important for the pathologist to be aware of these limitations.

[79] Oliverio S & Varlet V. New strategy for carbon monoxide poisoning diagnosis: carboxyhaemoglobin vs total blood carbon monoxide. Forensic Science International. 2019;306:110063

CO exposure and fetal, neonatal and childhood mortality

Children are more vulnerable to CO exposure than adults. Whether exposure occurs in utero, as a neonate or across other paediatric groups, the rapid uptake of CO in the blood, their high metabolic requirements, and small blood volume are some of the factors that put them at risk.

Exposure to CO *in utero* has been shown to have different effects at different stages of development. CO is known to retard growth and even at lower levels of maternal exposure, be implicated in premature birth, low birthweight, congenital malformations, and neonatal sudden infant death and neuro-developmental delay[80], and congenital malformations and fetal death can occur[81]. Fetal and neonatal death, congenital malformations and neuroglogical problems have been associated with acute maternal exposure[82, 83].

Congenital heart disease or defects of development of the heart occur in the womb and are diagnosed in at least 1 in 150 births, with further diagnoses occurring later in life. It is estimated that 1-2% of the population are affected by congenital heart disease or defects[84]. Heart disease is the biggest cause of perinatal and infant mortality from congenital anomalies. Raised levels of CO from environmental sources have been identified in smoking and non-smoking pregnant women. The effects of CO in utero on heart development shown in the scientific literature, indicates the potential for imperfect heart development in the exposed fetus and warrants further investigation.

Toxicological studies of the effects of CO exposure on the heart in the developing fetus are limited in number. However, it is well established that intra-uterine hypoxia causes abnormal development[85]. As maternal health is key for an optimum birth outcome, a reduction in maternal oxygen availability will have an impact on the developing fetus and this is what occurs when a mother is exposed to CO. Given the impact that diseases of the cardiovascular system have on population health, the impacts of CO on fetal cardiac development is important. The literature on fetal hypoxia suggests that low birthweight is also considered a risk factor for some diseases of the cardiovascular system[86]. Risk of poor cardiac outcomes include left or right cardiomegaly and increased heart weight[87, 88]. The importance of the developmental stage of the exposure and dose is important in terms of outcome. Penney et al, 1980, highlighted in an animal study the significance of pre-natal exposure and the additive effect of continued exposure post-natally on the heart, that differed from the reversibility of effects seen if the CO exposure ceased following birth[89]. Brain damage following maternal exposure to CO has been identified in fetal post mortems[90].

[80] UKTIS. Monograph Exposure to carbon monoxide in pregnancy. May 2017 www.medicinesinpregnancy.org

[81] Caravati E.M. et al. Fetal toxicity associated with maternal carbon monoxide poisoning. Ann.Emerg. Med 1988;17(7):714-7

[82] ibid

[83] Norman C.C. & Halton D.M Is carbon monoxide a workplace teratogen? Ann. Occup. Hyg.1990;34(4):335-47

[84] BHF. UK Factsheet 2020. www.bhf.org.uk (accessed February 2020).

[85] Hutter D. et al. Causes and mechanisms of intrauterine hypoxia and its impact on the fetal cardiovascular system: a review. Int.J . Paed 2010. doi;10.1155/2010/401323

[86] ibid

[87] Aubard Y. & Magne I. Carbon monoxide poisoning in pregnancy. BJOG 2005;107:7 doi. org.1111/j.1471-0528.2000.tb11078.x

[88] Penny D. et al. Temporary and lasting cardiac effects of pre- and postnatal exposure to carbon monoxide. Toxicol.Appl. Pharmacol. 1980; 53:271-278

[89] ibid

[90] Norman C.C. & Halton D.M Is carbon monoxide a workplace teratogen? Ann. Occup. Hyg.1990;34(4):335-47

Supporting the literature on lower level exposure to environmental CO, is the recording of exhaled breath CO levels in pregnant women at first booking (the first appointment with the midwife). Unfortunately, variables around the measurement recorded (such as endogenous CO levels, time since leaving home) cannot or are not currently captured. The scientific literature highlights the different effects associated with exposure that vary at different stages of development. This suggests that extending monitoring would be important. In particular, further work is required in the consideration of the in utero exposed fetus and the neonate who continues to be exposed in the home. This scenario is one that should be addressed by government to ensure the best start in life that incorporates protection from environmental CO *in utero*.

CONSIDERATION OF PROPOSED CORONIAL INVESTIGATION OF STILLBIRTHS AND CO

In March 2019, the consultation on coronial investigations on still births was opened. This followed the requirement for proper consideration on whether to give Coroners the powers to investigate stillbirths as a coronial investigation as a way to deliver an improved process in reducing the rate of avoidable stillbirths in England and Wales. The scope of the proposed investigation by Coroners is clearly defined to a gestation period from 37 weeks to post 42 weeks and is focussed on healthcare practices that could be changed and lessons learnt to prevent future stillbirths and improve the safety of, and care provided to pregnant women.

As was noted in 'Consultation on coronial investigations of stillbirths'[91], the majority (90%) of stillbirths occur before the onset of care in labour (antepartum). Factors that were noted as being associated with antepartum stillbirths included smoking, and suboptimal antenatal care that included a failure to identify babies at risk.

Consultation on the proposed document closed June 2019 and the outcome is currently being considered by government. The development of processes to prevent stillbirths is important regarding exposure to CO in light of the known effects that exposure to CO has on the developing baby and that it is an avoidable risk. If exposure to CO is suspected, remembering that the symptoms of CO exposure, whilst mimicking those more usually associated with, but not exclusively to, the earlier stages of pregnancy, suspicion should be raised. Scrutiny of maternal notes, and coronial investigation should help in determining the source and cause of exposure that might have otherwise gone undetected.

NICE guidance and current best practice requires the screening of pregnant women for CO at their booking visit (which usually occurs at 8-12 weeks of gestation). This is aimed at identifying women who are exposed to CO from environmental sources of CO. The screening of women at later stages in gestation is being developed, although improvements to the medical recording of exposures are required to facilitate the delivery of benefits from data analysis.

The potential that the collection and analysis of screening data has to inform and support a coronial investigation into a stillbirth is large: helping to underpin an underlying cause of avoidable death that ultimately could be important to the survival of other babies and the prevention of further exposure to other household occupants, that could include children.

[91] HM Government. Consultation on coronial investigations of stillbirths. March 2019 www.consult.justice.gov.uk

Considerations in the development of holistic data gathering and reporting of deaths from CO

CORONIAL INFORMATION AND DATA STORAGE OF MORTALITY STATISTICS

Coronial data in the UK

Currently, data logged by Coroners in England and Wales can be obtained from the Chief Coroner for England and Wales's annual bulletin, or from the Office of National Statistics (ONS); there is no sophisticated publicly available Coroners database that holds such information. However, it is important to note that these two sources of information differ as they are used for different purposes. Coronial data is used for the purposes of developing Coroners' policy, making it useful for central government and those involved in the appointment and payment of Coroners. Coronial data is also of interest to those with an interest in monitoring the volume and types of cases Coroners investigate[92].

Data collected by Coroners are submitted via statistical returns and include the following data: the number of deaths referred to the Coroner, the number of post-mortem examinations held (with reporting on the use of less invasive techniques), and the conclusions of inquests. Where inquests have not been concluded, the death is not included in the dataset. The data includes deaths of Nationals outside England and Wales. The collection of the data is used to monitor volume and types of cases that Coroners handle[93].

Office of National Statistics

ONS data is more often used by researchers to investigate public health mortality and policy development. ONS data provides statistics on all registered deaths in England and Wales irrespective of coronial investigation. Therefore, a death reported to a Coroner and the registration of a death following an inquest will be included after a time delay. Information from death certificates collected by ONS is used to measure the relative contributions of different diseases to mortality. The data provides important statistical information that can be used for monitoring the health of the population, research and in the design and evaluation of interventions for the improvement of public health.

[92] Ministry of Justice. Guide to Coroners Statistics 2019 www.justice.gov.uk

[93] ibid

The Prevention of Future Deaths Report

A Coroner has the power and the legal duty, to submit a report under Regulation 28 (formerly known as Rule 43) to prevent the occurrence of future deaths based on issues that are revealed during an investigation. If the belief is that action could have been taken to prevent that death from occurring and which, if taken, would prevent future deaths of a similar nature, a report is written. Responses to and actions taken in light of the findings by those that receive the report must be submitted. Scrutiny of these reports provide information that can be used to assist with the improvement of public health measures regarding exposure to CO, although currently, these reports are more likely to report only high level, acute exposures to CO. Assurance that the actions allocated to the nominated parties were both undertaken and appropriate, has to be followed up by the Coroner[94].

For CO, there have been a number of prevention of Future Deaths reports submitted by Coroners relating to high level exposures to CO. If there is to be increased scrutiny of death certificates that trigger investigative follow-up and the submission of Future Deaths reports, then CO stakeholders will need to establish interventions and training that will demonstrably reduce exposures, eradicate poor practice, improve awareness and embed positive change.

Examples of coronial information systems

Australia and New Zealand were the first countries to set up a National Coronial Information System (NICS), an internet-based database of coronial information. The establishment of the database followed the recognition that public health and safety could be improved if deaths of a similar nature could be identified. The NICS contains good quality data and provides detailed information on a range of deaths and is used extensively as an injury surveillance tool. However, its limitations are known and accounted for during research: data on open cases and missing information create the potential for selection and reporting biases that could preclude the identification and control of confounders[95]. The usefulness of the detail provided in the database was highlighted in a paper that considered heroin-related deaths in the NICS database[96]. The authors established that had their work relied on toxicology results alone, then they would have under-estimated the number of heroin-related deaths. The use of the NICS database enabled them to differentiate between heroin and pharmaceutical opioid overdose deaths, helping to improve understanding of the co-morbidities associated with these preventable deaths and highlighting an importance of differentiating between the types of overdose deaths that had implications for public health and policy intelligence. The work facilitated a strategic policy and public health response to tackle the issue. Similar parallels could, to some extent, be made with a database that contained data from multiple CO stakeholders.

A review of the NICS database shows that it has influenced policy, regulation and safety campaigns in a number of areas of public health spanning communicable and non-communicable diseases, and accidental deaths[97].

[95] Bugeja L. et al, The utility of medico-legal databases for public health research: a systematic review of peer-reviewed publications using the National Coronial Information System.Health Res. Policy Syst. 2016;14:28

[96] Roxburgh A. et al., Accurate identification of opioid overdose deaths using coronial data. Forensic Sci. Int., 2018;287:40-46

[97] Pearse J., The national coronial information system: a decade of challenges and achievements. Injury Prevention, 2012;18:A22

Public Health Surveillance in the UK

A core function of the UKHSA is surveillance to inform public health decision-making[98]. New systems of data collection for communicable and non-communicable diseases have been implemented to improve intelligence relating to the wider influences of public health. The development of the UKHSA public health surveillance system is one that should provide leverage for the requirement of data collection on CO related mortality.

The integration of healthcare sector and CO stakeholder data collection is key to the improvement of intelligence on deaths where CO exposure has played an important role in the causation of death. This acknowledgement that the integration of data collection is fundamental to the success of surveillance for the improvement of public health was clearly outlined by the Academy of Medical Sciences report *'Health of the Public in 2040'*[99]. Ensuring that the way in which the collection, storage, security, authenticity, access, and analysis of data is optimised and future-proofed, is fundamental to achieving this goal.

Database for CO

With the knowledge that collaboration and accurate data analysis will add positively to public health surveillance, understanding which partners and the roles of these partners involved in such a collaboration is important. In considering CO, it is apparent that many, (although not all) of the stakeholders have already been identified via the membership of the APPCOG sub-groups, although others can be identified in the recommendations provided in reports of the APPCOG and its sub-groups.

The role of government bodies and agencies in the regulation of domestic gas work already requires a reporting mechanism from the Gas Distribution Networks (GDNs). There is also capacity for improvement in the reporting of deaths where CO could be implicated as an underlying cause or contributor to events that resulted in death. Given that the scientific evidence has developed as regards our understanding of the effects of CO on health and in particular, of the long term impact on health and mortality, there is a need to take action. Therefore, by including the healthcare sector in the collection of data; capitalising on the potential to integrate this with Medical Examiner and Coroner reporting, could make the assessment of the impact of CO on morbidity and mortality a quantifiable prospect, particularly as the UKHSA already holds the remit for national surveillance.

On a global scale, there is currently less evidence of country wide legislation, regulation or monitoring to facilitate a similar process of reporting and surveillance as in the UK. This gives a UK system of surveillance a greater likelihood of being effective at this time.

However, due to the nature of the data and elements pertaining to its storage and use, it is apparent that linking databases amongst the stakeholders using decentralised ledger technology would appear sensible. Such data would lend itself to certain essential elements of decentralised technology such as authenticity, time stamping, security in light of sensitive data, provide secure access for a number of different purposes, including research. Developing and utilising AI to work on algorithms to scrutinise the database should also be considered as an important future development. Undertaking such work and seeking to overcome the current limitations of data sources would make a significant contribution to an understanding of the effects exposure to CO has on public health: a topic that by its nature, is difficult to address because of the number of variables associated with it.

[98] Public Health England. Public Health England: approach to surveillance 2017. www.phe.gov.uk (UKHSA since Oct 2021)

[99] Academy of Medical Sciences. Health of the public in 2040. 2016 www.acmedsci.ac.uk

Discussion

It is without doubt that solutions to the issues of exposure to CO and its associated effects on mortality need to be tackled. The scientific literature clearly shows that the effects of CO on health need to be better understood. Understandably, prevention of exposure is key, and whilst recorded data of mortality from high exposures to CO have steadily decreased, deaths continue to occur. Meanwhile, exposures to levels that do not immediately kill are not measured, although the use of data from research measuring CO in ambient indoor air, data from the domestic fuel, and alarm industries all point towards levels of exposure being enough to have effects on health. The nature of the effects are not as homogenous as those of other pollutants. Diagnosis is inherently difficult: CO is a mimic, the place where a health professional makes the diagnosis is not necessarily conducive to clearly establishing exposure. The potential for symptoms to be attributed to other factors are clear.

WHO in 2010, clearly raised the issue that there were effects on health from exposure to indoor sources of low level CO, by introducing a 24hr guideline that was clearly developed from the available scientific evidence. How this guideline should be monitored within homes has still to be realised.

There are clearly a number of stakeholders who can work together to confirm a diagnosis of exposure to CO. These are not exclusive to healthcare professionals, and include as examples first responders, gas engineers, and CO alarm helplines. An important indicator of exposure is an alarm sounding and this being reported and recorded. The difficulty lies in cases where there are fewer clues, particularly if the deceased had underlying health issues. Identification of exposure to CO that may have triggered, accelerated or worsened disease processes that resulted in death is much harder and is likely to require a significant development in biomarker research. However, information on the deceased's past CO exposure will help raise suspicion that CO exposure played an important factor in the chain of events leading to death.

Awareness and training that reduces the risk of exposure to CO and can result in a lasting behaviour change is critically important. This is needed for both professionals and the public who have a duty of care for service users or dependent family members.

That the UK has regulation and legislation that can positively impact on the prevention of CO exposure is very encouraging. For many other countries, this is not the case. However, exposure to CO at lethal and non-lethal levels to continue. Whilst there is legislation that should prevent illegal gas work, it is known that such practices continue and that such work poses a risk to occupant health. Improvements could be seen if the health effects of illegal gas work were identified in the healthcare setting. If the role of the Medical Examiner can raise suspicion that CO could be implicated as an underlying cause or important contributor to death, then a referral can be made to the Coroner. Training and the development of guidance in this area for Medical Examiners would go some way to supporting them in cases where CO could be implicated. If a referral to the Coroner was made, greater consideration would be required in the interpretation of %COHb results: the effect that this could have had on underlying health issues, and the possible impact of long term exposure on health. Ensuring that methods of detection are suitably accurate is important.

Scrutiny by the Medical Examiner is unlikely to impact on the final coding of death for CO. However, where CO is identified as being associated with a death in the community, the recording of this will be important to the protection of other occupants and the prevention of malpractice by engineers and landlords.

The power to trigger investigations also highlights the importance and usefulness of systems that record work electronically. SMART technology solutions that can assist in data collection are likely to become mainstream and could, if linked appropriately, provide the foundation on which to more easily conduct a physical investigation of a property and its appliances. Improving data collection, availability and interoperability would also assist Coroners in their role.

That there is now legislation that protects tenants from CO exposure in their homes is commendable and valuable. This is an important development in the drive to improve the standards of rented accommodation for health and safety purposes. However, as always, there are caveats to be aware of. For the tenant the Housing (fit for habitation) Act 2018, cannot be used if the CO exposure is as a result of improper behaviour by the tenant, or when the appliance has not been supplied by the landlord. Ensuring appropriate behaviour and maintenance of appliances is likely to be difficult in these situations. The extension of the regulation associated with CO alarms is also important through its requirements for social landlords. However, the unregulated owner-occupied domestic setting makes protection from CO harder.

The work undertaken by ENA highlights the drivers that can result in improper behaviour and lack of appliance maintenance associated with fuel poverty. Fuel poverty and CO should be tackled together.

Likewise, the safety of the home environment for pregnant women is of vital importance for maternal and fetal health. Knowing that CO impacts on birth outcomes that can have lifelong effects on health, should stimulate action to make the home environment a safe place for pregnant women. Further studies need to be undertaken to improve an understanding of the effects that in utero and neonatal exposure has on avoidable child mortality. That Coroners could have the powers to investigate stillbirths is important where CO is concerned, as identification of CO exposure would triggering an investigation that could identify work or practices that run counter to legislation. Protecting other occupants and safeguarding future pregnancies, is crucial. However, the sensitivity around the topic of stillbirth must be acknowledged. That screening of pregnant women is being undertaken is a very positive step in improving our understanding of CO levels in pregnant women, Extending the programme to include later gestational timepoints will potentially flag homes with problem appliances.

There is undoubtedly an enormous effort being put into interventions and programmes of work to prevent CO exposure and improve knowledge and awareness. These actions have generated a wealth of data that currently sit in isolation. Proper interrogation of these datasets by statisticians with an understanding of the variables associated with CO exposure, should be undertaken. This will also help improve communication of the risks associated with CO and help in the development of more effective awareness campaigns on a regional and local level. The filling of data gaps will improve knowledge and intelligence on CO exposure. Understanding the reasons why these data are not being collected is essential.

Data sharing will provide an enormous benefit to the study of CO as a public health problem, and as a cause of accidental death. To achieve this improvement, the storage of data that is accurate, collected systematically, authenticated and is cryptographically secure, lends itself to decentralised ledger platforms. Work to develop this should start.

The cost of accidental CO exposure to the health service is unknown. That CO exposure is avoidable makes it obvious that its occurrence has cost implications. Given what we know, these could be far higher than currently estimated.

Conclusion

Accidental poisonings by CO at lethal levels are investigated and recorded by the Coroner. The implementation of the Medical Examiner system, once rolled out into the community, should raise the profile of CO as a potentially important factor in a death at lower levels, if recommendations made within this report are supported and acted upon. Such action will encourage the provision of detailed information to assist in the scrutiny of the death certificate. If sufficient suspicion is raised that CO could be considered an important factor (underlying or contributory) in the death, the case is referred the Coroner. By developing a cryptographically secure decentralised ledger, the accurate, authenticated and timely provision of stakeholder data to the Coroner to inform the investigation would occur. It would also accelerate the investigation process. An additional benefit of such a tool would be the ability to interrogate the data and identify interventions, develop training and learning tools, and help inform the direction of research to underpin policy. Developing reporting pathways are essential to the success of legislation and regulation that protects people from exposure to CO. Ensuring that the aims of legislation and regulation do not fail because of a lack of a truly holistic approach to tackling CO, is important. England and Wales should capitalise on the fact that there is legislation and regulation in place to prevent exposure to CO. If implemented effectively, the morbidity and mortality effects of environmental exposure to CO should be greatly reduced, making the closing of loopholes that perpetuate illegal gas work imperative. By removing these loopholes and identifying lower levels of exposure that may be an underlying cause or contributory factor in a death, the data from death certificates will more accurately reflect the impact of CO exposure in the home. The analysis of such data naturally informs funding for healthcare development and research, but crucially, as data from death certificates are used to inform practices and policies at a local, regional, national, and global level, capitalising on opportunities to improve accuracy are important.

The Medical Examiner role has the potential to play an important role in the prevention of deaths where CO is implicated. Their work is likely to contribute to an improvement in public health, and ensure that England and Wales develop the measures required to protect its population from accidental exposures to environmental CO.