2018 02

Death in the line of duty... NIOSH

A report from the NIOSH Fire Fighter Fatality Investigation and Prevention Program January 25, 2019

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

Executive Summary

On March 17, 2017, at 1020 hours a 54-year-old male career firefighter (FF) responded to a structure fire in a 2½-story single family home. The FF coordinated interior attack operations, gave an in-person report to the Incident Commander, changed his air bottle, and returned to the interior to assist with overhaul. At 1041 hours, the FF collapsed while performing overhaul. Fellow firefighters immediately removed him from the fire room, transported him down stairs, and lifted him onto a stretcher that was brought to the front of the house. Firefighters initiated cardiopulmonary resuscitation (CPR) as the stretcher was wheeled to the ambulance. Paramedics provided advanced life support (ALS) protocols en route to the hospital, including cardiac medication and multiple defibrillations. The ambulance arrived at the hospital emergency department (ED) at 1058 hours. Hospital ED personnel continued resuscitation efforts unsuccessfully for approximately 30 minutes. The FF was pronounced dead on March 17, 2017, at 1126 hours.

The Medical Examiner's report and death certificate listed "carbon monoxide toxicity in a person with hypertensive and atherosclerotic cardiovascular disease" as the immediate cause of death. NIOSH concludes that the physical exertion associated with firefighting and the elevated levels of carbon monoxide (CO) in the presence of severe underlying cardiovascular disease likely triggered an arrhythmia in this FF.

Key Recommendations

- *Ensure that all firefighters receive an annual medical evaluation consistent with National Fire Protection Association (NFPA) 1582,* Standard on Comprehensive Occupational Medical Program for Fire Departments.
- *Ensure firefighters are cleared for duty by a physician knowledgeable about the physical demands of firefighting, the personal protective equipment used by firefighters, and the various components of NFPA 1582.*
- *Phase in a mandatory comprehensive wellness and fitness program for firefighters.*
- *Perform an annual physical performance (physical ability) evaluation.*
- *Provide annual medical clearance for self-contained breathing apparatus (SCBA) use.*
- *Ensure firefighters wear SCBA when working in a potentially hazardous atmosphere.*

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

Introduction

On March 17, 2017, at 1041 hours a 54-year-old male career FF collapsed while performing overhaul at a residential fire. The U.S. Fire Administration (USFA) notified NIOSH of this fatality on March 20, 2017. NIOSH contacted the affected fire department (FD) on March 24, 2017, and again on February 20, 2018, to gather additional information and to initiate the investigation. On March 8, 2018, a contractor for the NIOSH Fire Fighter Fatality Investigation and Prevention Program (the NIOSH investigator) conducted an on-site investigation of the incident.

During the investigation, the NIOSH investigator interviewed the following people:

- Fire Chief (who served as Incident Commander at the fire)
- Union President
- Firefighters who worked with the FF
- Wife of the FF
- Paramedic who provided care
- Medical Examiner

The NIOSH investigator reviewed the following documents:

- FD incident report
- Emergency medical service (ambulance) report
- Hospital ED records
- Primary care physician's records
- Death certificate
- Autopsy report

Investigation

On March 17, 2017, at 0800 hours the FF reported for his normally scheduled 24-hour shift. The FF was Command Aid to the Deputy Chief (DC). After routine station chores, the FF began his regular work, which included driving the DC to each of the fire stations. At 1004 hours, the DC and the FF responded to a motor vehicle accident (MVA). It was a relatively minor accident with no injuries. It was a clear, cool, and windy March day in Massachusetts, with an ambient temperature of 28.9°F, relative humidity of 35%, 18.4 mph wind speed, and wind chill of 16.5°F [Weather Channel no date]. At 1017 hours, a full box alarm (2 engines, 2 ladders, medic, and command vehicle) with a total of 14 firefighters was dispatched as a first alarm assignment for a 2½-story residential structure fire. A private ALS and BLS ambulance also responded to the scene to provide Emergency Medical Services. The DC and FF (command car) and Engine 2 responded from the scene of the MVA.

Apparatus from the initial response arrived at approximately 1026 hours and reported heavy fire showing from the second floor window on the A side of the building. The first ladder truck parked on the A side of the house and the two engines that were dispatched as part of the first response parked behind the ladder truck. The DC arrived on scene at approximately the same time and seeing the fire conditions, called for a second alarm that brought in another engine from his jurisdiction and additional resources (1 engine, 1 ladder truck, a squad unit, and a Deputy Chief) from neighboring communities so that another 10 firefighters were on scene. Engine 2 (E2) took an initial attack line into the structure through the front door. The FF entered the building as an aide to command to make observations of interior conditions and report back to the Incident Commander (IC). He also assisted moving the 1¾-inch attack line up to the second floor. After the lines were charged, the fire crews advanced toward the front of the house, entered the bedroom, and began extinguishing the fire. Engine 3 arrived on scene and began stretching another attack line. The crew of E2 exited the building to change their air bottles and the crew of Engine 1 (E1) continued to work the fire. The FF exited the building and reported to the DC, who was serving as IC, that the main fire had been knocked down but that they needed to do some clean up and look for extension. The FF showed no signs of distress and did not report anything out of the ordinary. He changed his air bottle and reentered the structure.

The FF was in the fire room working with several other firefighters from multiple apparatus. The fire was mostly contained but the firefighters were having some trouble finding fire extension in the wall void spaces and attic. The room had been vented and visibility was good but there was still smoldering material. The E1 Captain felt something fall against his leg and looked down to see a firefighter. He reached out to him thinking he had tripped on the hose line but when the FF did not respond, the E1 Captain shook him and asked, “Are you okay”. As the E1 Captain realized that the FF was unresponsive, he shouted to other firefighters for help and radioed the IC that there was a firefighter down. At this point, the E1 Captain could not easily identify the fallen firefighter because he was wearing his facepiece. The E1 Captain asked other firefighters in the room who the FF was. The E3 LT who was working alongside the FF who collapsed and had just finished speaking with him about some challenges with overhaul (the use of plywood instead of gypsum board) identified the FF and the E3 LT and E1 Captain dragged him out of the fire room and down the hallway. At the top of the stairs, they passed the FF to other firefighters who were on the stairs and he was carried to the first floor and out the front door.

The IC notified dispatch that there was a “firefighter down” at 1041 hours and instructed the private paramedics who had been dispatched as part of the box alarm to have the stretcher at the front of the house. He stepped inside to see who the FF was as he was being carried downstairs. The FF was brought to the front of the building, his SCBA tank was removed, CPR was initiated, he was placed on a stretcher, and CPR was continued as he was wheeled to the ambulance (about 300 feet from entrance of building).

Paramedics on scene initiated care at 1044 hours. Initial assessment found that the FF was pulseless, apneic, and unresponsive. The skin was pale and warm to the touch, and his pupils were dilated. Inside the ambulance, the paramedics attached the cardiac monitor to the FF. The initial rhythm was ventricular fibrillation (VFIB). The first defibrillation occurred at 1047 hours; the heart remained in VFIB. The FF was placed on a LUCAS™ device for automated chest compressions. An oropharyngeal airway was established and oxygen was provided via bag-valve mask. Intraosseous access was gained and cardiac medications (epinephrine and amiodarone) were administered (first round at 1049 hours). Additional defibrillations (4 total pre-hospital) and cardiac medications were administered en route to the hospital ED. Throughout treatment, the FF remained unresponsive, apneic, and pulseless.

The ambulance arrived at the ED at 1057 hours. Physical exam revealed that the FF was unresponsive, had no heart rhythm (asystole), and was not breathing. The FF was diaphoretic and cyanotic. A central IV line was placed and hydroxocobalamin (a form of vitamin B-12) was infused as an antidote for possible hydrogen cyanide poisoning. The FF was intubated with an endotracheal tube under direct visualization using a GlideScope® device. CPR was continued and the FF received additional rounds of epinephrine and amiodarone and bicarbonate without change in his clinical status. At 1126 hours, the FF was pronounced dead.

Medical Findings

The Medical Examiner's report and the death certificate listed the cause of death as "carbon monoxide toxicity in a person with hypertensive and atherosclerotic cardiovascular disease". The Medical Examiner found severe calcified atherosclerotic narrowing (> 95%) of three main coronary arteries (left anterior descending, circumflex, and right coronary artery) and a 2 cm (centimeter) area of pallor in the left ventricle indicating a "remote" myocardial infarction (heart attack). Left ventricular hypertrophy, with a left ventricular wall and inter-ventricular septal wall thickness of 1.7 cm, and a heart weight of 450 grams were also noted. Histology showed myocardial fibrosis, myocyte hypertrophy, and severe calcified coronary arteries. (See **Appendix A** for a more detailed description of autopsy findings.)

The FF often walked on the treadmill at the fire station on regular shift days (about 2 times per week) and regularly engaged in physical work (carpentry) and outdoor activities (hiking). He was being treated for hypertension and high cholesterol but rarely saw his primary care physician. At his most recent medical examination in March 2015, the FF had a blood pressure of 122/82 millimeters of mercury (mmHg) (normal is < 120/80; the hypertension treatment goal is usually < 130/80 [Whelton et al. 2017]). Blood work performed in March 2015 indicated the FF had a "borderline high" level of total cholesterol (total cholesterol = 205 milligrams per deciliter [mg/dL]; desirable < 200 mg/dL), a "near or above normal" level of low density lipoprotein (LDL = 117; optimal < 100 mg/dL), a high level of triglycerides (TG = 228 mg/dL; normal < 160 mg/dL), and blood glucose (88 mg/dL) within the normal range (< 100 mg/dL) [AHA 2015; Kratz et al. 2004]. He had a family history of coronary artery disease.

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

Based on his last medical evaluation (March 2015), he was 69 inches tall and weighed 218.6 pounds, giving him a body mass index (BMI) of 32.3 kilograms per meter squared (kg/m^2); a BMI of 30.0 or greater is considered to be obese [NHLBI no date-a].

Fire Department

At the time of the NIOSH investigation, the career FD consisted of over 85 uniformed personnel operating out of three fire stations. It served a population of approximately 35,000 in a geographic area of 4 square miles. In 2017, the FD responded to approximately 4,500 calls.

Employment and Training

Applicants must be 19–32 years of age, possess a valid state driver's license, have a high school diploma or equivalent, and take the State of Massachusetts civil service test. The list of applicants is sent to the FD and top ranked candidates are interviewed and subjected to a background test. Candidates who pass all of the above are offered conditional employment and undergo a psychological test and medical screening, and must complete a physical ability test (PAT). The medical screening meets the standards set forth by the Commonwealth of Massachusetts. The PAT is administered by the Commonwealth of Massachusetts and candidates must pass all stations of the test. New members are assigned to their position based on departmental vacancies. The FF had been with the FD for 21 years and Aid to the DC for 12 years. The FF completed the Massachusetts Firefighting Academy upon his hiring and was a Certified Firefighter I/II.

Medical Evaluation

The FD requires preplacement medical evaluations for new members. The evaluations are performed by a clinic that provides the medical evaluations on a contract basis. Components of the evaluation include the following:

- Complete medical history
- Physical examination (height, weight, blood pressure, pulse, and respiratory rate)
- Complete blood count
- Urinalysis
- Urine drug screen
- Audiogram
- Vision test
- Respirator use questionnaire
- Spirometry (pulmonary function testing)
- Resting electrocardiogram (EKG)
- Chest X-ray

When members join the FD, they are medically cleared to wear SCBA and are fit tested.

The FD does not require periodic medical evaluations for members beyond the initial hiring medical evaluation. Members must provide medical clearance through a contracted clinic following a serious injury. Members must provide medical clearance through their own health care provider following a serious illness. The FD does not perform yearly fit testing or provide medical clearance to wear SCBA.

Wellness and Fitness Programs

There is fitness equipment in the fire stations and firefighters are permitted to use the equipment whenever their schedules permit. The FD does not offer a wellness/fitness program.

Discussion

Sudden Cardiac Events

In the United States, atherosclerotic coronary heart disease (coronary artery disease) is the most common risk factor for cardiac arrest and sudden cardiac death [Myerburg and Castellanos 2008]. Risk for its development is grouped into non-modifiable and modifiable risk factors. Non-modifiable risk factors include age older than 45 (for men; age > 55 for women), male gender, and family history of coronary artery disease. Modifiable risk factors include diabetes mellitus, smoking, high blood pressure (hypertension), unhealthy blood cholesterol levels, and obesity/physical inactivity [AHA 2016; NHLBI no date-b]. The FF was male, over age 45, had a family history of cardiovascular disease, had hypertension, and hypercholesterolemia.

Coronary Artery Disease

Coronary artery disease refers to atherosclerotic plaque in the coronary arteries and the complications of the plaque. The narrowing of the coronary arteries by atherosclerotic plaques occurs over many years, typically decades [Libby 2013]. However, the growth of these plaques probably occurs in a nonlinear, often abrupt fashion. Plaque buildup that restricts blood flow and prevents sufficient oxygen delivery to the myocardium causes ischemia, and can cause chest pain (angina), particularly with exertion. Heart attacks or myocardial infarctions typically occur with the sudden development of complete blockage (occlusion) in one or more coronary arteries that have not developed a collateral blood supply. This sudden blockage is primarily due to blood clots (thromboses) forming on top of a ruptured atherosclerotic plaque [Libby 2013]. Heart attacks and sudden cardiac death can be triggered by heavy physical exertion [Albert et al. 2000; Mittleman et al. 1993; Willich et al. 1993], including snow shoveling [Franklin et al. 2001] and firefighting activity [Kales et al. 2003, 2007; NIOSH 2007].

Establishing the occurrence of an acute heart attack requires any of the following: characteristic EKG changes, elevated cardiac enzymes, or coronary artery thrombus/plaque rupture. In this case, the FF did not have evidence of an acute heart attack, but his autopsy revealed evidence of a prior heart attack.

Left Ventricular Hypertrophy/Cardiomegaly

Left ventricular hypertrophy (LVH), thickening of the heart's left ventricle, is a common finding among individuals with long-standing high blood pressure, a heart valve problem, obesity, or cardiac ischemia (reduced blood and oxygen supply to the heart muscle) [Cramariuc and Gerdts 2016; Cuspidi et al. 2014; Korre et al. 2016; Siegel 1997; Tavora et al. 2012]. Cardiomegaly refers to an enlarged heart and is often defined as a heart weighing more than 450 grams. LVH and cardiomegaly are both structural heart changes that increase the risk for arrhythmias and sudden cardiac death [Chatterjee et al. 2014; Kahan and Bergfeldt 2007; Spirito et al. 2009; Tavora et al. 2012]. The FF had severe LVH and cardiomegaly.

Occupational Medical Standards for Structural Firefighters

Nearly half of all firefighter duty-related deaths are caused by sudden cardiac death. Firefighting results in multiple cardiovascular changes that could lead to plaque rupture or arrhythmogenic changes in individuals with underlying cardiovascular disease [Smith et al. 2016]. Research on firefighter fatalities have found that autopsies have shown atherosclerosis in the majority of coronary heart disease-related fatalities [Geibe et al. 2008; Kales et al. 2003]. More recent research also indicates that the majority of firefighter fatalities due to sudden cardiac death have cardiomegaly [Yang et al. 2013]. To reduce the risk of sudden cardiac events or other incapacitating conditions among firefighters, the NFPA developed 1582, *Standard on Comprehensive Occupational Medical Program for Fire Departments* [NFPA 2013a, 2018]. In regard to screening asymptomatic firefighters for coronary artery disease, NFPA 1582 recommends basing this decision on risk. At the time of this fatality, for firefighters (such as the FF) with two non-modifiable risk factors (male of age > 45 years), the presence of just one additional risk (e.g., hypertension, high cholesterol, diabetes, or smoking) was enough to recommend screening with a symptom-limiting exercise stress test (EST) [NFPA 2013a].

The FD did not require medical evaluations for members, and the FF rarely saw a physician. The FF had hypertension and hypercholesterolemia. The most recent medical evaluation that was performed (March 2015) indicated that his hypertension was well controlled. Still, given the presence of two risk factors in a male over age 45, an EST would have been recommended according to NFPA 1582 guidance at the time. Guidance in the new (2018) edition of NFPA 1582 recommends that all firefighters age ≥ 40 be assessed annually for cardiovascular risk using the Heart Risk Calculator from the American College of Cardiology/American Heart Association (ACC/AHA); those with intermediate risk, i.e., 10-year risk of 10%–19%, should undergo further evaluation with an EST to ≥ 12 metabolic equivalents (METs), with or without imaging [NFPA 2018a]. The FF did have an EST test in 2007 due to chest pain. That stress test lasted for 12 minutes (estimated maximal aerobic capacity [VO_{2max}] = 42.3 milliliters per kilogram per minute or 12 METs [Heyward and Gibson 2014]) and did not result in any arrhythmias or ischemic changes.

Carbon Monoxide

Carbon monoxide (CO) is a tasteless, colorless, odorless, nonirritating gas that is produced by the incomplete combustion of carbon compounds [Kao and Nañagas 2006; Rose et al. 2017]. When inhaled, CO crosses the alveolar (lung) membrane and binds to hemoglobin (Hb), forming carboxyhemoglobin (COHb). CO has multiple detrimental effects on the body: CO has an affinity for hemoglobin that is more than 200 times greater than oxygen, thus it decreases the ability of hemoglobin to carry oxygen; it shifts the oxygen dissociation curve to the left, thereby decreasing oxygen delivery to the tissue; and it is toxic and leads to cellular damage [Hampson et al. 2012; Kao and Nañagas 2006; Roderique et al. 2015].

Blood levels of CO differ depending upon environmental exposures. Values of 1%–2% are typical of non-smoking city residents, whereas smokers may have CO values of 4%–9% [Varon et al. 1999; Widdop 2002]. The FF in this case was a nonsmoker. Common symptoms of CO exposure include headache, nausea, and fatigue, and these can progress to confusion, altered mental status, and death [Hampson et al. 2012]. Increasing COHb levels are generally associated with increasing symptom severity (see **Table 1**). Low COHb levels (15%–20%) generally correlate with mild symptoms, and high levels (60%–70%) are associated with severe symptoms, including death. However, intermediate COHb levels do not correlate well with signs/symptoms of CO poisoning or with clinical outcomes [Benignus et al. 1987; Hampson 2016; Kao and Nañagas 2006; Roderique et al. 2015]. Symptom severity is related to the concentration of CO and duration of exposure. Exertion can hasten CO uptake due to the larger volume of air inhaled per minute [King and Simpson 1997]. A patient with a high COHb level after a brief, high concentration exposure may not manifest any clinical toxicity whereas someone with this COHb level after prolonged, low-level exposure may be more symptomatic [Kao and Nañagas 2006]. It is also important to realize that COHb levels may not accurately reflect exposure level if the patient has been treated with oxygen [Kao and Nañagas 2006].

Table 1. Signs and symptoms associated with carbon monoxide poisoning

Mild	Moderate	Severe
• Headache	• Confusion	• Palpitations
• Nausea	• Syncope	• Dysrhythmias
• Vomiting	• Chest pain	• Hypotension
• Dizziness	• Dyspnea	• Myocardial ischemia
• Blurred vision	• Weakness	• Cardiac arrest
	• Tachycardia	• Respiratory arrest
	• Tachypnea	• Non-cardiogenic pulmonary edema
	• Rhabdomyolysis	• Seizures
		• Coma

Source: Kao and Nañagas [2006]

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

One of the reasons that COHb levels do not correlate directly to clinical symptoms is because CO affects multiple organs and does so through multiple physiological mechanisms in addition to binding to hemoglobin to form COHb [Roderique et al. 2015; Rose et al. 2017]. The organs that are most sensitive are those with the highest metabolic rate and oxygen demands – such as the brain and the heart [Huzar et al. 2013]. Elevated CO levels have several detrimental effects on the cardiovascular system. Significant exposures to CO can lead to hypotension, dysrhythmia, ischemia, infarction, and in extreme cases, cardiac arrest [Kao and Nañagas 2006]. CO exerts these affects through multiple mechanisms: it binds to myoglobin, reducing oxygen availability, which impairs heart function and increases the risk of arrhythmia and eventual myocardial infarction with prolonged ischemia; it can cause vascular dysfunction, which further reduces coronary blood flow; and it disrupts electrical stability [Huzar et al. 2013; Rogerique et al. 2015]. CO exposure exacerbates underlying cardiovascular disease, making individuals with this disease especially vulnerable to cardiac issues [Atkins and Baker 1985; Kao and Nañagas 2006; Thom and Keim 1989].

Firefighting is unlike other occupations because firefighters are exposed to dozens of chemical exposures and these differ from fire to fire. The products of combustion at a fire may include natural materials, polyvinyl chloride (PVC), flame retardants, fillers, plasticizers, and dozens of other synthetic materials. Furthermore, combustion is a complex chemical/physical process in which the materials and the conditions under which they are burned greatly affect the resulting products. The concentration of products of combustion is largely a function of the amount of oxygen present and the thermal energy transferred to the burning material; hence, knowing the composition of the fire atmosphere at any given fire at any given time is nearly impossible [Lees 1995]. It is known, however, that the incomplete combustion of carbonaceous fuel produces an abundance of CO. The NIOSH recommended immediately dangerous to life and health (IDLH) concentration for CO is 1,200 parts per million (ppm) [NIOSH 2016]. Researchers have reported levels of 70,000 ppm in the room of origin during a fire and levels of > 10,000 ppm in a room that was remote from the fire [Alarie 2002]. Recently, CO levels up to 2,500 ppm were reported outside the fire room during fire suppression and victim removal in a realistic modern fire environment [Horn et al. 2013].

The COHb levels resulting from exposure depend on CO concentration and length of exposure. NIOSH recommends a time weighted average exposure limit of 35 ppm and a ceiling limit of 200 ppm [Kuschner and Blanc 2014]. In investigating cause of death from fire, a COHb level of ≥ 50% has been relied on to determine CO as the principle cause of death and as evidence that a victim perished as a result of smoke inhalation, although as noted above, there is wide variability in COHb levels of fire victims [Alarie 2002; Anderson et al. 1981]. Evaluating autopsies from individuals who died in the MGM Grand Hotel Fire in Las Vegas found that approximately 70% of victims had a COHb of ≤ 40% [Alarie 2002]. Administration of hydroxocobalamin as an antidote for possible hydrogen cyanide poisoning may interfere with measured COHb levels; elevated CoHb levels may appear minimally changed or falsely lowered on co-oximetry, according to research by Pace et al. [2014].

At autopsy, the FF was found to have a COHb level of 43%. Such a high level of COHb could present significant medical issues in its own right, and is particularly problematic in an individual with severe underlying cardiovascular disease. The FD has a standard operating guideline (SOG) that reads "Firefighting personnel that are operating in an IDLH area will be in full personal protective equipment, with SCBA donned and operating before entering an IDLH or potential IDLH area." All firefighters working with the FF reported that he was wearing his facepiece when he collapsed during overhaul. This is further supported by the paramedic who helped carry the FF down the stairs and reported that the FF's facepiece came off while he was being carried down the stairs. The FF was not breathing at this time, so it does not appear that his CO exposure occurred during this time.

The high levels of COHb found at autopsy suggest that the FF was not on air the entire time he was in the structure although there are no reports of anyone seeing him without his mask on. Although not reported by FD members, it is possible that the FF might have removed his mask for some period of time while he was operating on the first floor during his initial entry to the building. However, the FF exited the building and changed his air bottle, so he was evidently on air for much of his initial entry and there were no signs or symptoms of CO exposure at this time. The FF was wearing his mask when he collapsed but he may have operated in the building without using his mask for some period of time after re-entering the building. At this point, the fire had been knocked down but the smoldering material in the bedroom would likely have been producing very high levels of CO. There was no soot found in his airway, suggesting that he did not inhale a large quantity of smoke. It is possible that his high CO levels could reflect contamination of the breathing air fill source. This can occur with portable air compressors with an intake close to the exhaust of a fuel-fired engine. This is an unlikely explanation, however, since no other firefighters suffered any symptoms of elevated CO at the fire.

It is unclear exactly when the FF was exposed to CO and the precise role of elevated CO in this FF's death is unknown. The FF had severe atherosclerotic heart disease, including evidence of a prior myocardial infarction, as well as evidence of severe left ventricular hypertrophy. Both the physical exertion of firefighting and elevated COHb levels are potential triggers for precipitating sudden cardiac events in vulnerable individuals.

Recommendations

***Recommendation #1: Ensure that all firefighters receive an annual medical evaluation consistent with NFPA 1582,* Standard on Comprehensive Occupational Medical Program for Fire Departments.**

Discussion: Guidance regarding the content and frequency of these medical evaluations can be found in NFPA 1582 [NFPA 2018a]. These evaluations are performed to determine a fire fighter's medical ability to perform duties without presenting a significant risk to the safety and health of himself/herself or others. This medical evaluation should be consistent with the requirements of NFPA 1582.

Recommendation #2: Ensure firefighters are cleared for duty by a physician knowledgeable about the physical demands of firefighting, the personal protective equipment used by firefighters, and the various components of NFPA 1582.

Discussion: According to NFPA 1582, the FD should require that physicians are familiar with the physical demands of firefighting and the risks that firefighters encounter and should guide, direct, and advise members with regard to their health, fitness, and suitability for duty [NFPA 2018a]. The physician should review job descriptions and essential job tasks required for all FD positions to understand the physiological and psychological demands of firefighting and the environmental conditions under which firefighters perform, as well as the personal protective equipment (PPE) they must wear during various types of emergency operations.

Fire service and medical experts developed a tool to assist primary care physicians and other community providers who take care of firefighters away from the FD. The *Healthcare Provider's Guide to Firefighter Physicals* provides information on the physical, environmental, and mental stress of firefighting and the unique occupational health risks firefighters face due to the demands of their job. The guide is a helpful first step to orient primary care providers to firefighter health issues and can be downloaded free from the Firefighter Safety Through Advanced Research (FSTAR) website [IAFC 2017].

Recommendation #3: Phase in a mandatory comprehensive wellness and fitness program for firefighters.

Discussion: Guidance for fire department wellness/fitness programs to reduce risk factors for cardiovascular disease and improve cardiovascular capacity is found in NFPA 1583, *Standard on Health-Related Fitness Programs for Fire Department Members* [NFPA 2015]; the *Fire Service Joint Labor Management Wellness/Fitness Initiative* [IAFF and IAFC 2018]; the *Health and Wellness Guide for the Volunteer Fire and Emergency Services* [USFA 2009]; and in *Firefighter Fitness: A Health and Wellness Guide* [Schneider 2010]. Worksite health promotion programs have been shown to be cost effective by increasing productivity, reducing absenteeism, and reducing the number of work-related injuries and lost workdays [Aldana 2001; Stein et al. 2000]. Health promotion programs for firefighters have been shown to reduce coronary heart disease risk factors and improve fitness levels, with mandatory programs showing the most benefit [Blevins et al. 2006; Dempsey et al. 2002; Womack et al. 2005].

The FD has exercise equipment available to members but does not have a wellness/fitness program.

Recommendation #4: Perform an annual physical performance (physical ability) evaluation.

Discussion: NFPA 1500 recommends fire department members who engage in emergency operations be annually evaluated and certified by the FD as having met the physical performance requirements identified in paragraph 10.2.3 of the standard [NFPA 2013b, 2018b]. This is recommended to ensure firefighters are physically capable of performing the essential job tasks of structural firefighting. The physical ability test could be incorporated into the FD's training program.

Recommendation #5: Provide annual medical clearance for SCBA use.

Discussion: The Occupational Safety and Health Administration (OSHA) Revised Respiratory Protection Standard requires employers to provide medical evaluations and clearance for employees using respiratory protection [29 CFR 1910.134]. These clearance evaluations are required for private industry employees and only for public employees in states operating OSHA-approved state plans. Because Massachusetts does not operate a state OSHA plan [OSHA 2018], the fire department is not required to provide medical evaluations for employees using respirators. However, we recommend voluntary compliance with this recommendation to improve firefighter health and safety.

Recommendation #6: Ensure firefighters wear SCBA when working in a potentially hazardous atmosphere.

Discussion: NFPA 1500 [NFPA 2013b, 2018b] states, "When engaged in any operation where they could encounter atmospheres that are immediately dangerous to life or health (IDLH) or where the atmosphere is unknown, the fire department shall provide and require all members to use SCBA that has been certified as being compliant with NFPA 1981" [NFPA 2013c]. Such operations would include roof ventilation and other areas subject to smoke and gases.

References

AHA [2016]. Understand your risks to prevent a heart attack. Dallas, TX: American Heart Association, http://www.heart.org/HEARTORG/Conditions/HeartAttack/UnderstandYourRiskofHeartAttack/Understand-Your-Risk-of-Heart-Attack_UCM_002040_Article.jsp.

Alarie Y [2002]. Toxicity of fire smoke. Crit Rev Toxicol *32*(4):259–289.

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

Albert CM, Mittleman MA, Chae CU, Lee IM, Hennekens CH, Manson JE [2000]. Triggering of sudden death from cardiac causes by vigorous exertion. N Engl J Med *343*(19):1355–1361, http://dx.doi.org/10.1056/NEJM200011093431902.

Aldana SG [2001]. Financial impact of health promotion programs: a comprehensive review of the literature. Am J Health Promot *15*(5):296–320, http://dx.doi.org/10.4278/0890-1171-15.5.296.

Anderson RA, Watson AA, Harland WA [1981]. Fire deaths in the Glasgow area: ii the role of carbon monoxide. Med Sci Law *21*(4):288–294.

Atkins EH, Baker EL [1985]. Exacerbation of coronary artery disease by occupational carbon monoxide exposure: a report to two fatalities and a review of the literature. Am J Ind Med *7*(1):73–79.

Benignus VA, Kafer ER, Muller KE, Case MW [1987]. Absence of symptoms with carboxyhemoglobin levels of 16–23%. Neurotoxicol Teratol *9*(5):345–348.

Blevins JS, Bounds R, Armstrong E, Coast JR [2006]. Health and fitness programming for fire fighters: does it produce results? Med Sci Sports Exerc *38*(5):S454.

Chatterjee S, Bavishi C, Sardar P, Agarwal V, Krishnamoorthy P, Grodzicki T, Messerli FH [2014]. Meta-analysis of left ventricular hypertrophy and sustained arrhythmias. Am J Cardiol *114*(7):1049–1052, http://dx.doi.org/10.1016/j.amjcard.2014.07.015.

Cramariuc D, Gerdts E [2016]. Epidemiology of left ventricular hypertrophy in hypertension: implications for the clinic. Expert Rev Cardiovasc Ther *14*(8):915–926, http://dx.doi.org/10.1080/14779072.2016.1186542.

Cuspidi C, Rescaldani M, Sala C, Grassi G [2014]. Left-ventricular hypertrophy and obesity: a systematic review and meta-analysis of echocardiographic studies. J Hypertens *32*(1):16–25, http://dx.doi.org/10.1097/HJH.0b013e328364fb58.

Dempsey WL, Stevens SR, Snell CR [2002]. Changes in physical performance and medical measures following a mandatory firefighter wellness program. Med Sci Sports Exerc *34*(5):S258.

Franklin BA, George P, Henry R, Gordon S, Timmis GC, O'Neill WW [2001]. Acute myocardial infarction after manual or automated snow removal. Am J Cardiol *87*(11):1282–1283, https://doi.org/10.1016/S0002-9149(01)01520-X.

Geibe JR, Holder J, Peeples L, Kinney AM, Burress JW, Kales SN [2008]. Predictors of on-duty coronary events in male firefighters in the United States. Am J Cardiol *101*(5):585–589, http://dx.doi.org/10.1016/j.amjcard.2007.10.017.

Hampson NB, Piantadosi CA, Thom SR, Weaver LK [2012]. Practice recommendations in the diagnosis, management, and prevention of carbon monoxide poisoning. Am J Respir Crit Care Med *186*(11):1095–1101, http://dx.doi.org/10.1164/rccm.201207-1284CI.

Hampson NB [2016]. Myth busting in carbon monoxide poisoning. Am J Emerg Med *34*(2):295–297.

Heyward VH, Gibson AL [2014]. Advanced fitness assessment and exercise prescription, 7th ed. Champaign: Human Kinetics.

Horn GP, Kerber S, Fent KW, Fernhall B, Smith DL [2013]. Interim report: cardiovascular & chemical exposure risks in modern firefighting. Champaign: Illinois Fire Service Institute – IFSI Research, University of Illinois at Urbana-Champaign.

Huzar TF, George T, Cross JM [2013]. Carbon monoxide and cyanide toxicity: etiology, pathophysiology and treatment in inhalation injury. Expert Rev Respir Med *7*(2):159–170, http://dx.doi.org/10.1586/ers.13.9.

IAFC [2017]. Healthcare provider's guide to firefighter physicals. Fairfax, VA: International Association of Fire Chiefs, Firefighter Safety Through Advanced Research (FSTAR), http://www.fstaresearch.org/resource/?FstarId=11591.

IAFF, IAFC [2018]. The fire service joint labor management wellness/fitness initiative. 4th ed. Washington, DC: International Association of Fire Fighters, International Association of Fire Chiefs.

Kahan T, Bergfeldt L [2005]. Left ventricular hypertrophy in hypertension: its arrhythmogenic potential. Heart *91*(2):250–256, http://dx.doi.org/10.1136/hrt.2004.042473.

Kales SN, Soteriades ES, Christoudias SG, Christiani DC [2003]. Firefighters and on-duty deaths from coronary heart disease: a case control study. Environ health *2*(1):14, https://dx.doi.org/10.1186%2F1476-069X-2-14.

Kales SN, Soteriades ES, Christophi CA, Christiani DC [2007]. Emergency duties and deaths from heart disease among firefighters in the United States. N Engl J Med *356*(12):1207–1215, http://dx.doi.org/10.1056/NEJMoa060357.

Kao LW, Nañagas KA [2006]. Toxicity associated with carbon monoxide. Clin Lab Med *26*(1):99–125, https://doi.org/10.1016/j.cll.2006.01.005.

King D, Simpson BJ [1997]. Scientific basis for an air quality standard for carbon monoxide. REPORT-CONCAWE-WHITE SPECIAL INTEREST, https://www.concawe.eu/wp-content/uploads/2017/01/rpt_97-51-2004-01704-01-e.pdf.

Korre M, Porto LGG, Farioli A, Yang J, Christiani DC, Christophi CA, Lombardi DA, Kovacs RJ, Mastouri R, Abbasi S, Steigner M, Moffatt S, Smith D, Kales SN [2016]. Effect of body mass index on left ventricular mass in career male firefighters. Am J Cardiol *118*(11):1769–1773, http://dx.doi.org/10.1016/j.amjcard.2016.08.058.

Kratz A, Ferraro M, Sluss PM, Lewandrowski KB [2004]. Case records of the Massachusetts General Hospital. Weekly clinicopathological exercises. Laboratory reference values. N Engl J Med *351*(15):1548–1563, http://dx.doi.org/doi:10.1056/NEJMcpc049016.

Kuschner WG, Blanc PD [2014]. Gases & other airborne toxicants. In: LaDou J, Harrison RJ, eds. Current Diagnosis & Treatment Occupational & Environmental Medicine. 5th ed. New York: McGraw-Hill Education.

Lees PSJ [1995]. Combustion products and other firefighter exposures. Occup Med *10*(4):691–706, PubMed PMID: 8903743.

Libby P [2013]. Mechanisms of acute coronary syndromes and their implications for therapy. N Engl J Med *368*(21):2004–2013, http://dx.doi.org/10.1056/NEJMra1216063.

Myerburg RJ, Castellanos A [2008]. Cardiovascular collapse, cardiac arrest, and sudden cardiac death. In: Fauci AS, Braunwald E, Kasper DL, Hauser SL, Longo DL, Jameson JL, Loscalzo J, eds. Harrison's principles of internal medicine. 17th ed. New York: McGraw-Hill.

Mittleman MA, Maclure M, Tofler GH, Sherwood JB, Goldberg RJ, Muller JE [1993]. Triggering of acute myocardial infarction by heavy physical exertion. N Engl J Med *329*(23):1677–1683, http://dx.doi.org/10.1056/NEJM199312023292301.

NFPA [2013a]. Standard on comprehensive occupational medical program for fire departments. Quincy, MA: National Fire Protection Association. NFPA 1582.

NFPA [2013b]. Standard on fire department occupational safety and health program. NFPA 1500. Quincy, MA: National Fire Protection Association.

NFPA [2013c]. Standard on open-circuit SCBA for emergency services. NFPA 1981. Quincy, MA: National Fire Protection Association.

NFPA [2015]. Standard on health-related fitness programs for fire department members. NFPA 1583. Quincy, MA: National Fire Protection Association.

NFPA [2018a]. Standard on comprehensive occupational medical program for fire departments. NFPA 1582. Quincy, National Fire Protection Association.

NFPA [2018b]. Standard on fire department occupational safety and health program. NFPA 1500. Quincy, MA: National Fire Protection Association.

NHLBI [no date-a]. Calculate your body mass index. Bethesda, MD: U.S. Department of Health and Human Services, National Institutes of Health, National Heart, Lung, and Blood Institute, https://www.nhlbi.nih.gov/health/educational/lose_wt/BMI/bmi-m.htm.

NHLBI [no date-b]. Who is at risk for coronary heart disease? Bethesda, MD: U.S. Department of Health and Human Services, National Institutes of Health, National Heart, Lung, and Blood Institute, http://www.nhlbi.nih.gov/health/health-topics/topics/cad/atrisk.html.

NIOSH [2007]. NIOSH alert: preventing fire fighter fatalities due to heart attacks and other sudden cardiovascular events. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2007-133, http://www.cdc.gov/niosh/docs/2007-133.

NIOSH [2016]. Carbon monoxide. Online pocket guide to chemical hazards. Washington, DC: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) online publication, https://www.cdc.gov/niosh/npg/npgd0105.html.

OSHA [2018]. OSHA-approved state plans. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/dcsp/osp/index.html.

Pace R, Bon Homme M, Hoffman RS, Lugassy D [2014]. Effects of hydroxocobalamin on carboxyhemoglobin measured under physiologic and pathologic conditions. Clin Toxicol (Phila) *52*(7):647–650, http://dx.doi.org/doi:10.3109/15563650.2014.939659.

Roderique JD, Josef CS, Feldman MJ, Spiess BD [2015]. A modern literature review of carbon monoxide poisoning theories, therapies, and potential targets for therapy advancement. Toxicology *334*:45–58, http://dx.doi.org/10.1016/j.tox.2015.05.004.

Rose JJ, Wang L, Xu Q, McTiernan CF, Shiva S, Tejero J, Gladwin MT [2017]. Carbon monoxide poisoning: pathogenesis, management, and future directions of therapy. Am J Respir Crit Care Med *196*(3):398–399, http://dx.doi.org/10.1164/rccm.201606-1275CI.

Schneider EL [2010]. Firefighter fitness: a health and wellness guide. New York: Nova Science Publishers.

Siegel RJ [1997]. Myocardial hypertrophy. In: Bloom S, ed. Diagnostic criteria for cardiovascular pathology acquired diseases. Philadelphia, PA: Lippincott-Raven.

Smith DL, DeBlois JP, Kales SN, Horn GP [2016]. Cardiovascular strain of firefighting and the risk of sudden cardiac events. Exerc Sport Sci Rev *44*(3):90–97, http://dx.doi.org/10.1249/JES.0000000000000081.

Spirito P, Autore C, Rapezzi C, Bernabò P, Badagliacca R, Maron MS, Bongioanni S, Coccolo F, Estes NA, Barillà CS, Biagini E, Quarta G, Conte MR, Bruzzi P, Maron BJ [2009]. Syncope and risk of sudden death in hypertrophic cardiomyopathy. Circulation *119*(13):1703–1710, http://dx.doi.org/10.1161/CIRCULATIONAHA.108.798314.

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

Stein AD, Shakour SK, Zuidema RA [2000]. Financial incentives, participation in employer sponsored health promotion, and changes in employee health and productivity: HealthPlus health quotient program. J Occup Environ Med *42*(12):1148–1155, PMID: 11125677.

Tavora F, Zhang Y, Zhang M, Li L, Ripple M, Fowler D, Burke A [2012]. Cardiomegaly is a common arrhythmogenic substrate in adult sudden cardiac deaths, and is associated with obesity. Pathology *44*(3):187–191, http://dx.doi.org/10.1097/PAT.0b013e3283513f54.

Thom SR, Keim LW [1989]. Carbon monoxide poisoning: a review epidemiology, pathophysiology, clinical findings, and treatment options including hyperbaric oxygen therapy. J Toxicol Clin Toxicol *27*(3):141–156.

USFA [2009]. Health and wellness guide for the volunteer fire and emergency services. Emmitsburg, MD: Federal Emergency Management Agency, U.S. Fire Administration. Publication No. FA-321, https://www.usfa.fema.gov/downloads/pdf/publications/fa_321.pdf.

Varon J, Marik PE, Fromm RE Jr, Gueler A [1999]. Carbon monoxide poisoning: a review for clinicians. J Emerg Med *17*(1):87–93, https://doi.org/10.1016/S0736-4679(98)00128-0.

Weather Channel [no date]. Historical weather. Weather Underground, The Weather Company, http://www.wunderground.com/history.

Whelton PK, Carey RM, Aronow WS, Casey DE Jr, Collins KJ, Dennison Himmelfarb C, DePalma SM, Gidding S, Jamerson KA, Jones DW, MacLaughlin EJ, Muntner P, Ovbiagele B, Smith SC Jr, Spencer CC, Stafford RS, Taler SJ, Thomas RJ, Williams KA Sr, Williamson JD, Wright JT Jr [2017]. 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: a report of the ACC/AHA Task Force on Clinical Practice Guidelines. J Am Coll Cardiol *71*(19):e127–e248, http://dx.doi.org/10.1016/j.jacc.2017.11.006.

Widdop B [2002]. Analysis of carbon monoxide. Ann Clin Biochem *39*(Pt 4):378–391, http://dx.doi.org/10.1258/000456302760042146.

Willich SN, Lewis M, Lowel H, Arntz HR, Schubert F, Schroder R [1993]. Physical exertion as a trigger of acute myocardial infarction. N Engl J Med *329*(23):1684–1690, http://dx.doi.org/10.1056/NEJM199312023292302.

Womack JW, Humbarger CD, Green JS, Crouse SF [2005]. Coronary artery disease risk factors in firefighters: effectiveness of a one-year voluntary health and wellness program. Med Sci Sports Exerc *37*(5):S385.

Yang J, Teehan D, Farioli A, Baur DM, Smith D, Kales SN [2013]. Sudden cardiac death among firefighters ≤45 years of age in the United States. Am J Cardiol *112*(12):1962–1967, http://dx.doi.org/10.1016/j.amjcard.2013.08.029.

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

Investigator Information

This incident was investigated by the NIOSH Fire Fighter Fatality Investigation and Prevention Program, Cardiac and Medical LODD Component within the Division of Surveillance, Hazard Evaluations, and Field Studies, located in Cincinnati, Ohio. Denise L. Smith, PhD, led the investigation and authored the report. Dr. Smith is Tisch Distinguished Professor of Health and Exercise Sciences and Director of the First Responder Health and Safety Laboratory at Skidmore College in New York. She is also a member of the NFPA Technical Committee on Fire Service Occupational Safety and Health. Dr. Smith was working as a contractor with NIOSH during this investigation. Wendi Dick, MD, MSPH, provided medical consultation and contributed to the report. Dr. Dick is Medical Officer for the Cardiac and Medical LODD Component.

Disclaimer

Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health (NIOSH). In addition, citations to websites external to NIOSH do not constitute NIOSH endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH is not responsible for the content of these websites.

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

Appendix A
Autopsy Findings

- Coronary artery disease
  - Generalized severe calcified arteriosclerotic plaque
    - Left anterior descending artery (LAD) > 95% stenosis
    - Circumflex artery (CFX) > 95% stenosis
    - Right coronary artery (RCA) > 95% stenosis
  - Up to 2.0 cm area of pallor of posteromedial left ventricular myocardium, consistent with remote myocardial injury
- Structural heart disease
  - Cardiomegaly (heart weighed 450 grams)
  - Left ventricular hypertrophy (left ventricular thickness of 1.7 cm)
- Microscopic:
  - Myocardial fibrosis
  - Sub-endocardial ischemia
  - Myocyte hypertrophy
  - Severe calcific atherosclerotic narrowing of coronary arteries
- Normal cardiac valves
- Mild atherosclerosis of aorta and cerebral arteries
- No evidence of a pulmonary embolus (blood clot in the lung arteries)
- Neck – upper airway is patent and without soot, edema or foam
- Carbon monoxide toxicity
- Blood analysis:
  - Carboxyhemoglobin – 43%
  - Negative for drugs of abuse

Author notes:
Predicted normal heart weight is 389 grams (ranges between 294 grams and 513 grams as a function of sex and body weight), according to research in Silver and Silver [2001].

Left ventricular thickness of 1.7 centimeters (cm) is high on the basis of postmortem studies by Kitzman et al. [1988] (normal range 1.07 cm–1.39 cm, average 1.23 cm).

The level of carboxyhemoglobin (COHb) in the blood is usually < 3% in nonsmokers (< 10% in smokers) [Kao and Nañagas 2006].

54-Year-Old Firefighter Suffers Carbon Monoxide Toxicity and Cardiac Event During Overhaul––Massachusetts

REFERENCES

Kao LW, Nañagas KA [2006]. Toxicity associated with carbon monoxide. Clin Lab Med *26*(1):99–125, https://doi.org/10.1016/j.cll.2006.01.005.

Kitzman DW, Scholz DG, Hagen PT, Ilstrup DM, Edwards WD [1988]. Age-related changes in normal human hearts during the first 10 decades of life. Part II (maturity): a quantitative anatomic study of 765 specimens from subjects 20 to 99 years old. Mayo Clin Proc 63(2):137–146, PMID: 3276974.

Silver MM, Silver MD [2001]. Examination of the heart and of cardiovascular specimens in surgical pathology. In: Silver MD, Gotlieb AI, Schoen FJ, eds. Cardiovascular pathology. 3rd ed. Philadelphia, PA: Churchill Livingstone.