Cardiovascular Disease in US Firefighters: A Systematic Review

Elpidoforos S. Soteriades, MD,*† Denise L. Smith, PhD,‡§ Antonios J. Tsismenakis, MA,*¶ Dorothee M. Baur, MD,*¶ and Stefanos N. Kales, MD, MPH*¶

Abstract: Cardiovascular disease (CVD) is the leading cause of on-duty death among firefighters (45% of on-duty fatalities) and a major cause of morbidity. CVD in the fire service also has adverse public safety implications as well as significant cost impacts on government agencies. Over the last decade, our understanding of CVD among firefighters has significantly improved and provides insight into potential preventive strategies. The physiology of cardiovascular arousal and other changes that occur in association with acute firefighting activities have been well-characterized. However, despite the strenuous nature of emergency duty, firefighters' prevalence of low fitness, obesity, and other CVD risk factors are high. Unique statistical approaches have documented that on-duty CVD events do not occur at random in the fire service. They are more frequent at certain times of day, certain periods of the year, and are overwhelmingly more frequent during strenuous duties compared with nonemergency situations. Moreover, as expected on-duty CVD events occur almost exclusively among susceptible firefighters with underlying CVD. These findings suggest that preventive measures with proven benefits be applied aggressively to firefighters. Furthermore, all fire departments should have entry-level medical evaluations, institute periodic medical and fitness evaluations, and require rigorous return to work evaluations after any significant illness. Finally, on the basis of the overwhelming evidence supporting markedly higher relative risks of on-duty death and disability among firefighters with established coronary heart disease, most firefighters with clinically significant coronary heart disease should be restricted from participating in strenuous emergency duties.

Key Words: CVD, risk factors, firefighters

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Firefighting is widely recognized as a hazardous occupation. There are more than 1 million Americans involved in this essential public service. Most US firefighters are volunteers (72%), while 28% are career firefighters.1,2 On-duty fatalities in the US fire service are split roughly along the same proportions between volunteer and career members.2,3 Intuitively, one might think that most on-duty deaths result from burns and smoke inhalation. However, cardiovascular disease (CVD) is the single most frequent cause of duty-related fatalities, accounting for almost half of all fatalities, with 90% caused by coronary heart disease (CHD).4 Additionally, for every fatal on-duty heart disease (HD) event, there are an estimated 17 nonfatal, line-of-duty cardiovascular (CV) events in the US fire service.5 Some major metropolitan fire departments experience as many as 12 to 20 chest pain or cardiac hospitalizations per 1000 person-years (1.5–2 cases/mo in roughly 1200–1450 firefighters) [personal communication]. Given the team dynamic involved in firefighting, on-duty health events involve not only the affected team member, but also potentially jeopardize the performance and safety of coworkers. In addition, existing legislation often provides benefits to firefighters who die in the line of duty, retire due to CV causes, or simply develop a CV diagnosis.6,7 For example, in one major city, the frequency of HD and hypertension workers compensation claims in the fire department has ranged from 6% to 10% of all members every year over 6 years [personal communication]. Thus, CVD among firefighters is of importance to the fire service, the medical community, and to society at large because of the considerable financial and legal implications.

Physicians evaluating firefighters may face questions fairly unique to this occupation. What determines whether an individual is fit enough to safely join the fire service? Does the evidence support aggressive management of firefighters’ CVD risk factors? What determines whether a firefighter can safely return to emergency duties after a CVD event? When is an HD event causally related to the occupation of firefighting?

To better care for firefighters, this evidence-based review discusses the hazards of firefighting and their associated CV strain, the current prevalence and control of CVD risk factors among firefighters, CVD epidemiology relative to firefighting, and recommendations for prevention and management of CVD. Because the profession continues to be comprised predominantly of men, most of the research conducted on firefighters and summarized here is from male subjects.

OCCUPATIONAL HAZARDS, EXPOSURES, AND STRESSORS

Firefighters are prone to certain behaviors, unique working conditions, and hazardous exposures that may increase their CV risks.8 In general, these can be divided into acute and chronic stressors (Table 1).

Chronic Stressors

Inadequate Physical Activity

Regular physical exercise of sufficient duration is widely accepted to promote cardioprotection. However, infrequent and inadequate amounts of physical activity are commonplace in the fire service. Firefighters often experience long sedentary periods and most departments do not mandate exercise, have regular exercise

From the *Department of Environmental Health, Environmental and Occupational Medicine and Epidemiology (EOMIE), Harvard School of Public Health, Boston, MA; †Department of Occupational and Environmental Medicine, Cyprus Institute of Biomedical Sciences (CIBS), Nicosia, Cyprus; ‡Department of Health and Exercise Sciences, Skidmore College, Saratoga Springs, NY; §University of Illinois, Fire Service Institute, Champaign, IL; ¶The Cambridge Health Alliance, Harvard Medical School, Employee Health and Industrial Medicine, Cambridge, MA; and †Department of Occupational and Environmental Medicine, Boston University, School of Medicine, MA.

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Correspondence: Stefanos N. Kales, MD, MPH, Director, Employee Health & Industrial Medicine, The Cambridge Health Alliance, 1495 Cambridge St, Macht 427, Cambridge, MA 02139. E-mail: skales@challiance.org or skales@hsph.harvard.edu.

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TABLE 1. Potential Occupational Cardiovascular Hazards in Firefighters

<table>
<thead>
<tr>
<th>Chronic</th>
<th>Acute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long sedentary periods</td>
<td>Irregular physical exertion</td>
</tr>
<tr>
<td>Smoke exposure</td>
<td>Smoke exposure</td>
</tr>
<tr>
<td>(gaseous and particulate)</td>
<td>(gaseous and particulate)</td>
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<tr>
<td>Noise</td>
<td>Noise</td>
</tr>
<tr>
<td>Shift work/partial sleep deprivation</td>
<td>Excess heat/dehydration</td>
</tr>
<tr>
<td>Fire house dietary patterns</td>
<td>Duty-specific hazards</td>
</tr>
<tr>
<td>Occupational stress</td>
<td>Firefighting activities</td>
</tr>
<tr>
<td>Post-traumatic stress disorders</td>
<td>Physical training</td>
</tr>
<tr>
<td>High job demand and low decision control</td>
<td>Alarm response</td>
</tr>
</tbody>
</table>

regimens, or require the maintenance of discrete physical fitness parameters after hire. Furthermore, discretionary time for exercise may be largely consumed by overtime and second jobs. Inadequate physical activity makes firefighters prone to increased fat mass and the metabolic syndrome. Moreover, obese firefighters are more susceptible to further weight gain1 and associated decrements in health.9,10 This is especially pertinent within the current obesity epidemic, where recruits come from an increasingly heavy, less-fit general public.11 While sedentary behavior promotes atherosclerosis over the long-term, it also increases the risk of acute events.

Irregular bouts of strenuous activity in otherwise sedentary individuals are a known precipitant of acute coronary events,12 as are periods of high emotional stress.13 Indeed, firefighters are many times more likely to experience CVD events during periods of high psychological or physical stress, such as alarm response or fire suppression/active firefighting.4 The concept of firefighting precipitating or “triggering” cardiac events is reviewed in the proceeding discussion on strenuous duties.

Poor Dietary Habits

The unpredictable nature of emergency work leads to unreliable meal times, making the expediency of “fast-food” an unavoidable choice during certain work-shifts. In addition, working in shifts makes career firefighters more likely to consume more meals with higher fat and carbohydrate content.14 Shift workers have significantly increased triglyceride, free-fatty acid, and glucose levels and lower mean HDL-cholesterol.15 Moreover “firehouse culture” is known for recipes high in fat and dense in simple, refined carbohydrates. In one study, despite good awareness that dietary choices can mitigate CV risk, 37% of the firefighters surveyed reported that they enjoyed their current diets and had no desire to change.16

Shift Work

Career emergency responders commonly perform two 24-hour shifts per week or rotating shifts, and growing evidence from other occupations supports the association between shift work and an increased risk of CVD.17–19 The mechanisms are likely multifactorial (psychosocial, behavioral, and direct physiological pathways) including altered dietary habits and sleep disruption favoring metabolic syndrome, as well as less physical activity, higher stress levels, and altered circadian rhythms.14,15 In addition to shift work, second jobs and overtime details (commonly performed in between regular fire shifts) can further contribute to chronic partial sleep deprivation. Finally, sleep may also be affected by the psychological stress of public safety work.20 Sleep disturbance or deprivation has been associated with insulin resistance, weight gain, hypertension, and CVD.21–28

Smoke Exposure

The exposure to smoke during firefighting work, consisting of gases and particulates, was previously a more significant hazard and therefore was considered an important contributor to on-duty CVD.29 In recent decades, smoke exposure has been significantly reduced by the mandated use of the self-contained breathing apparatus during fire attack and suppression (aka, “knockdown”) operations. However, firefighters often do not wear self-contained breathing apparatus or other respirators during “overhaul,” the period immediately after fire suppression when the site is inspected for remaining sources of potential reignition. During overhaul, various noxious inhalants have been documented to still be present.30,31 Smoke inhalation can produce tissue hypoxia due to carbon monoxide, cyanide, and direct hypoxemia leading to myocardial ischemia in those with underlying CVD.32 Additionally, particulates have been associated with autonomic dysfunction, including increased heart rate, decreased heart rate variability, and the promotion of arrhythmias.33–35

Although the long-term CV consequences of smoke exposure in firefighters have not been adequately examined, plausible mechanisms for increased CVD related to chronic smoke exposure exist, including the increased formation of free radicals, subsequent endothelial dysfunction, increased coagulability, and increased progression of atherosclerosis.36 Therefore, firefighters are strongly encouraged to wear personal protective equipment during all activities with smoke exposure.

Noise

Noise is another intermittent exposure with negative CV impact, primarily by increasing blood pressure.37 Alarms, sirens, vehicle engines, and mechanized rescue equipment typically produce average noise exposures in the 63 to 85 dBA range. Personal monitors have consistently documented intermittent exposures in excess of 90 dBA (the federal permissible exposure limit for an 8-hour time-weighted average), and as high as 116 dBA.38 It has been estimated that for each 5 decibel increase in acute occupational noise exposure, there is a corresponding acute increase of 0.51 mm Hg in systolic blood pressure.39 Thus, siren noises potentially elevate systolic blood pressure by 5.9 to 11.8 mm Hg.40 There is general agreement that the hemodynamic effects of intermittent occupational noise persist during active exposure.41 However, whether these pressor effects are longstanding42 or relatively short-lived43 has yet to be clearly elucidated.37

Psychological Stress

Firefighters are also exposed to a variety of psychological stressors in the course of various emergencies, including fires, natural disasters, terrorism, rescue, and the provision of emergency medical services. High occupational demands, coupled with low decisional latitude in Karasek’s classic “demand-control” model, potentially contribute to increased stress levels, leading to elevated heart rate and blood pressure, as well as poor sleep.34 Susceptible firefighters exposed to more extreme stressors may develop post-traumatic stress disorder, associated with further adverse effects on heart rate, blood pressure, and the metabolic syndrome.35–37

Acute Cardiovascular Strain of Firefighting

Firefighting duties directly challenge the CV system, beginning with the alarm bell’s activation of the sympathetic nervous system, the physical workload of firefighting, and associated heat stress and dehydration (Fig. 1). Individual physiologic responses are F1 determined largely by the underlying medical status and cardiopulmonary fitness of each firefighter.
Sympathetic Activation

Structural fires are chaotic, noisy, low-visibility work environments with severe time limitations, and life-threatening conditions promoting “fight or flight responses.” Thus, sympathetic activation is a crucial mediator of altered physiology during firefighting. In one early study, researchers documented that firefighters achieved maximally predicted heart rates during emergencies, including one subject who sustained >188 beats per minute for a 15-minute period.46 Several groups have confirmed that heart rates increase dramatically following the initial alarm and reach maximal or near-maximal predicted values during simulated or actual fire emergencies.49–51

Physical Workload

Structural firefighting includes forcible entry, search and rescue, structure ventilation, and fire attack and suppression. Such work requires high levels of both dynamic aerobic and static physical exertion (climbing, crawling, squatting, moving and lifting heavy items, and using heavy tools). Moreover, these duties are performed wearing heavy, insulating personal protective equipment (PPE) often weighing in excess of 25 kg. Thus, firefighting PPE adds to the metabolic and thermal demands of firefighting. Studies of simulated firefighting tasks suggest that the minimum aerobic capacity as measured by oxygen consumption (VO₂) necessary to safely perform firefighting duties ranges from 33.9 to 45 mL/kg/min (9.7–12.8 METS [1 MET = 3.5 mL/kg/min]).52–55

A recent study measured oxygen consumption during a series of simulated firefighting tasks at a self-selected pace and found that firefighters averaged 62% of their VO₂max (29 mL/kg/min) over 8.5 minutes.56 At the end of the activity, oxygen consumption averaged 31.5 mL/kg/min, but ranged widely (12.5–53.1 mL/kg/min), with a significant inverse correlation between VO₂ max and performance time. Thus, fitter firefighters safely completed the tasks in less time. Among a carefully selected sample of firefighters, 100% of subjects with a VO₂ max <34 mL/kg/min (9.7 METS) failed a standard firefighting physical abilities test (PAT).56 The National Fire Protection Association (NFPA) has suggested 12 METS (approximately 42 mL/kg/min VO₂) as the minimum exercise capacity required for the safe performance of firefighting.57 A recent cohort study of professionally active career firefighters found more than one-third have aerobic capacities ≤12 METS.58 Longitudinal studies have been initiated to objectively determine “safe” fitness levels on the basis of the relative risk of future health and employment outcomes.

Heat

Firefighters produce large amounts of metabolic heat while working, and insulating PPE severely limits heat dissipation. Furthermore, fire-related heat contributes to additional thermal strain. Most studies of firefighting effects on core temperature have used relatively short bouts (18–38 minutes) of activity in training fires.59–61 These data suggest that core temperatures increase at a rate of approximately 0.05°C/min or 1.0°C over 20 minutes of acute firefighting activities. This degree of hyperthermia increases CV strain. During longer fire operations, this rate of core temperature increase can produce serious heat-related injuries and/or illness.

Several factors predispose to heat illness, including obesity, low levels of physical fitness, dehydration, lack of acclimatization, previous history of heat illness, and sleep deprivation.62 Furthermore, medical conditions such as diabetes, sweat gland dysfunction, viral illness, diarrhea, sunburn, and cardiac disease as well as medications that impair thermoregulation, including stimulants, anticholinergic, and certain CV drugs further increase the risk.62,63

Dehydration

Dehydration is closely related to heat stress and decreases plasma volume, further impairing thermoregulation and resulting in hemococoncentration. Because of encapsulating PPE, firefighters often sweat profusely, as much as 1.2 to 1.9 L/h during strenuous firefighting activity.49,59,64 Smith et al49 reported a 15% reduction in plasma volume after 3 bouts of strenuous firefighting activity that can have significant physiologic impacts, such as decreased stroke volume. In a series of three, 7-minute training drills with live fires, stroke volume decreased to almost 20% below baseline by the end of the trial, despite a 10-minute break to cool down and ingest fluids between the second and third bout of firefighting.49 Of particular concern with regard to dehydration are several fire service reports suggesting that firefighters are often relatively dehydrated even before they begin firefighting activity.65–68

Dehydration also leads to hemococoncentration associated with an increase in the concentration of several biochemical parameters.49 Firefighting is also associated with approximately 25% increase in circulation platelet numbers and activity likely attributable to hemococoncentration and increased sympathetic nervous activity along with an increase in several coagulatory variables.65,69 Thus, firefighting has the potential to acutely increase prothrombotic tendencies, which is potentially important for firefighters with underlying vascular disease.

In summary, firefighting activity leads to hyperthermia, dehydration, and considerable CV strain. In a susceptible individual, the CV strain associated with firefighting activity may trigger a sudden cardiac event through several biologically plausible pathways: increased shear stress may cause rupture of vulnerable plaque, hypercoagulability may lead to platelet aggregation and clot formation, or the increase in myocardial oxygen demand associated with firefighting may exceed myocardial oxygen supply.

STANDARD CVD RISK FACTORS AMONG FIREFIGHTERS

On-duty CVD events and premature retirements related to HD occur almost exclusively among susceptible firefighters with underlying CVD (whether overt and previously diagnosed or thereforie, unrecognized and “subclinical”). Accordingly, firefighters suffering adverse CV-related job events have been shown to have an excess of discrete CVD risk factors compared with control firefighters (Table 2).6,70,71
Smoking

Smoking is a major risk factor for CVD. Not surprisingly, some US States have passed legislation prohibiting firefighters hired subsequent to the passage of these laws from smoking tobacco. However, smoking continues to be a problem in the fire service, both among veteran firefighters “grandfathered” out of smoking prohibitions, in jurisdictions without such restrictions, and among volunteers. The prevalence of current smoking in recent firefighter studies ranges from 10% to 18% among general cohorts, whereas the prevalence is 40% to 50% among those succumbing to on-duty CHD fatalities.70,71,73 Thus, smoking has been demonstrated to be a strong independent risk factor for on-duty CHD events, CHD-related retirements, and for CHD event case-fatality among firefighters (Table 2).

Hypertension

Hypertension is universally accepted as a major risk factor for CVD, with increasing risk starting in the prehypertensive range.74–76 Approximately, 50% of firefighters have prehypertension, and 20% to 30% are hypertensive, a proportion expected to increase due to the obesity epidemic.77,78 Hypertension is also inadequately controlled in these professionals. In a prospective investigation, almost 75% of firefighters with hypertension lacked adequate blood pressure control,79 similar to the general population.79–83 Moreover, in the absence of criteria requiring proactive blood pressure management, the control of hypertension did not improve over the course of 4-year follow-up.78 In the above career firefighter cohort,78 2% to 5% had stage 2 hypertension, whereas surveys of volunteer firefighters have found 4% to 9% with stage 2 blood pressure readings.82

Higher blood pressures have been associated with CVD risk factor clustering, including older age, dyslipidemia, insulin resistance, and glucose intolerance.8,9,10,83–85 Hence, total aggregate CHD risk is greater among hypertensive firefighters than would be expected based upon the blood pressure alone. Accordingly, hypertension is an independent predictor of adverse employment outcomes: disability retirements due to HD, incident CHD, nonfatal myocardial infarction, and on-duty CHD fatalities (Table 2).7,67,83–88

Evidence suggests that hypertension-associated risks are concentrated among individuals with uncontrolled, rather than controlled, hypertension. A roughly 3-fold increase in adverse job outcomes with hypertension (combined outcome including on-duty death, injured on-duty, termination of duty, resignation, premature retirement, incident CV event) was attributable largely to firefighters with stage 2 hypertension who were not taking antihypertensive medications.83 Likewise, among on-duty CHD fatalities, left ventricular hypertrophy and/or cardiomegaly were found in 56% of firefighters who had undergone an autopsy, suggesting chronically uncontrolled hypertension.79 In Massachusetts, chronically uncontrolled hypertension and hypertensive HD were responsible for 8% of CV disability retirements, representing a third of CV pensions awarded to firefighters for non-CHD causes.84 Nonetheless, similar to the general population, the majority of incident CVD events that occur among emergency responders occur in persons who are initially prehypertensive or only mildly hypertensive, with average pressures in the range of 140 to 146/88 to 92 mm Hg.32

Obesity

Obesity is another well-established CVD risk factor, associated with cardiometabolic risk factor clustering.9–11 Obesity and increased body mass index (BMI) are also risk factors for job-related disability,89 incident CHD,90 on-duty CHD events70,88 and CVD retirements.9 (Table 2). However, the prevalence of obesity among firefighters has been increasing steadily over time within the overall obesity epidemic, so that roughly 40% of firefighters are now obese.9,10 In the 1980s and early 1990s, the average veteran had a BMI of 25.4 to 26.7 kg/m².86,87 but by 1996–1997, mean BMI had increased to almost 29 kg/m².9,10 and by 2001, it was 29.7 kg/m².9 Today, even much younger firefighter recruits (mean age, 26 years) have an average BMI of 28.5 kg/m² (Fig. 2). A recent population-based investigation of career and volunteer firefighters—using BMI, waist circumference, and body fat measures—proved that the high obesity prevalence was not due to the misclassification of increased muscle mass.92 Contrary to common wisdom in the fire service, obesity was even more prevalent when assessed by body fat rather than BMI, and the misclassification of muscular firefighters as obese by BMI was infrequent.

Among emergency responder recruits, 44% were overweight and 33% were obese, and in this cross-sectional study, obese subjects had an almost 7-fold greater risk of hypertensive blood pressure readings as compared with normal weight subjects (16% vs. 2.4%).11 Another recent study of young firefighters (29.7 ± 8.0 years), that excluded hypertensive subjects, showed similar results regarding the prevalence of overweight and obesity.77 Additionally, central and peripheral blood pressure were higher, while aortic and carotid artery stiffness were increased in those firefighters in the top tertile of BMI.97 Finally, with obesity prevalence among firefighters ranging from 30% to 40% and more than 90% of them being male, significant number of obese responders have or are expected to develop obstructive sleep apnea,93 another risk factor for hypertension, CHD, and increased mortality.94

Dyslipidemia

Dyslipidemia is another prevalent risk factor among firefighters, although their mean total cholesterol levels decrease over time from values of 200 to 220 mg/dL to 180 to 200 mg/dL, perhaps because of more frequent statin use.52,95 The prevalence of low HDL (<40 mg/dL) has been found to be 26% to 31%, whereas high fasting triglycerides (≥150 mg/dL) have been found in more than 20% of firefighters.95,96 The assessment of lipid abnormalities as an independent risk factor in retrospective studies of on-duty CHD events and CHD-related retirements has been limited because many of the firefighters suffering from these events lacked premorbid lipid values for comparison. Nonetheless, in unadjusted analyses, high total cholesterol (≥200 mg/dL) is associated with a 2.4-fold and 4.4-fold increased risk of CHD retirement and on-duty CHD death, respectively.6,7 Likewise, in a prospective study, firefighters who developed CHD had significantly higher total cholesterol, LDL, and triglycerides.86

### TABLE 2. Relative Risk of Cardiovascular Outcome by Risk Factor

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>On-Duty CHD Fatalities</th>
<th>Non-CHD Cardiovascular Retirements OR (95% CI)</th>
<th>CHD Retirements OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current smoking</td>
<td>8.6 (4.2–17)</td>
<td>2.5 (1.2–5.1)</td>
<td>3.9 (2.5–6.2)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>12 (5.8–25)</td>
<td>11 (6.1–20)</td>
<td>5.4 (3.7–7.9)</td>
</tr>
<tr>
<td>Obesity, BMI ≥30</td>
<td>3.1 (1.5–6.6)</td>
<td>3.6 (2.0–6.4)</td>
<td>1.4 (0.96–2.19)</td>
</tr>
<tr>
<td>Cholesterol ≥5.18 mmol/L (200 mg/dL)</td>
<td>4.4 (1.5–13)</td>
<td>1.1 (0.51–2.24)</td>
<td>2.4 (1.6–3.6)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>10.2 (3.7–28)</td>
<td>7.7 (2.9–20)</td>
<td>13 (6.1–28)</td>
</tr>
<tr>
<td>Prior diagnosis of CHD</td>
<td>35 (9.5–128)</td>
<td>NA</td>
<td>30 (9.5–96)</td>
</tr>
</tbody>
</table>

| Age ≥45-yr-old | 18 (8.5–40) | 26 (13–51) | 63 (35–111) |

CHD indicates coronary heart disease.
Diabetes Mellitus

The frequency of hyperglycemia (fasting glucose ≥110 mg/dL) in firefighters may be as low as 1%, while others have found the prevalence of type II diabetes mellitus (DM 2) to be 3% to 4%. As expected, the prevalence of DM 2 among firefighters succumbing to on-duty CHD events and CHD retirements is much higher: 21% and 26%, respectively. DM 2 is associated with an unadjusted 10- to 13-fold increased risk of on-duty CHD death or CHD retirement (Table 2). However, after multivariate adjustment, DM 2 is not a significant independent predictor in retrospective studies. Thus, DM 2-associated risks are likely mediated through concurrent effects on blood pressure, lipid metabolism, and previously established atherosclerotic disease.

Established CHD and CHD Equivalents

Peripheral artery disease, carotid stenosis, and history of thrombotic stroke or transient ischemic attack, diagnosed before a subsequent on-duty event or later retirement, are considered together for risk assessment purposes. The prevalence of established CHD is as low as 1% among career firefighters, but as high as 9% among volunteers. However, among firefighters experiencing fatal and nonfatal on-duty CHD events, previously diagnosed CHD accounts for 31% and 18% of cases, respectively, and is a strong independent risk factor for subsequent on-duty CHD events, on-duty CHD case-fatality, and CHD-related retirements (Table 2). Preexisting evidence of myocardial damage due to past infarction is associated with a roughly 2-fold increased risk of case fatality (ie, whether an on-duty event results in death or nonfatal disability).

Age

Increasing age is a robust, independent predictor of adverse CVD outcomes in firefighters, even after multivariate adjustment for all other risk factors (Table 2) and adjustment for types of duty performed, during or just prior to the onset of the CHD event (Fig. 3). Although the relationship of age to CVD and mortality is obvious, it deserves emphasis, because most current preventive and selective efforts in the fire service consist of medical and physical abilities standards required of young recruits at the lowest relative risk. Conversely, relatively few departments require periodic testing of veterans, and even when they do, they usually do not require stringent physical fitness requirements for maintaining active duty.

OCCUPATIONAL EPIDEMIOLOGY OF CVD IN THE FIRE SERVICE

Firefighting and the Lifetime Risk of CVD

A classic methodology for evaluating the occupational risks of certain diseases is to compare the morbidity and/or mortality attributable to said disease(s) in a particular occupation to that found in the general population or a comparable occupational cohort free of the exposures/risks expected in the index profession. Although “presumed” by the fire service and by many legal jurisdictions (see legal issues below) that firefighters have an elevated lifetime risk of CVD, the evidence is inconclusive and does not, on balance, support
such a hypothesis. Similar to the general population, CVD accounts for about 35% of firefighters' lifetime mortality.98–105

These cohort mortality studies of firefighters have failed to demonstrate any consistent increased risk of CVD death: firefighters' standardized mortality ratio for CHD is approximately 0.9 or 10% lower when compared with that of the general population.106 It has been argued that these “negative” findings are likely because of the “healthy worker effect”. In other words, based on medical and physical abilities selection criteria that must be passed to join the fire service, as well as the health benefits of being occupationally active, firefighters are expected to enjoy greater wellbeing. Therefore, they have a lower risk of morbidity and mortality than the general population, which includes individuals not occupationally active, and those with significant infirmities and disabilities.105–107

Proportionate On-Duty CVD Mortality

Proportionate on-duty CVD mortality refers to the proportion or percentage of deaths attributable to CVD etiologies occurring while on-duty. There is unanimous agreement that firefighters experience the highest proportionate mortality due to CVD while on-duty compared with other occupational groups and other public safety services workers, and all occupations combined have been reported to have a lower risk of morbidity and mortality than the general population, which includes individuals not occupationally active, and those with significant infirmities and disabilities.105–107

<table>
<thead>
<tr>
<th>Type of Duty</th>
<th>Kales et al71 (Relative Risk of CHD Death)</th>
<th>Holder et al6 (Relative Risk of Heart Event Leading to Retirement)</th>
<th>Kales et al71 (Relative Risk of CHD Death)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire suppression—OR (95% CI)</td>
<td>64.1 (7.4–556)</td>
<td>51 (12–223)</td>
<td>53 (40–72)</td>
</tr>
<tr>
<td>Physical training—OR (95% CI)</td>
<td>7.6 (1.8–31.3)</td>
<td>0.68 (0.2–2.7)</td>
<td>5.2 (3.6–7.5)</td>
</tr>
<tr>
<td>Alarm response—OR (95% CI)</td>
<td>5.6 (1.1–28.8)</td>
<td>6.4 (2.5–17)</td>
<td>7.4 (5.1–11)</td>
</tr>
<tr>
<td>Alarm return—OR (95% CI)</td>
<td>3.4 (0.8–14.7)</td>
<td>0.37 (0.07–1.8)</td>
<td>5.8 (4.1–8.1)</td>
</tr>
<tr>
<td>EMS and other non-fire emergencies—OR (95% CI)</td>
<td>1.7 (0.5–5.9)</td>
<td>0.75 (0.3–1.8)</td>
<td>1.3 (0.9–2.0)</td>
</tr>
<tr>
<td>Firehouse and other non-fire emergencies—OR (95% CI)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

CHD indicates coronary heart disease; EMS, emergency medical service; OR, odds ratio; CI, confidence interval.

Circadian and Seasonal On-Duty CHD Patterns

Complementary evidence supporting that emergency duties can precipitate CVD fatalities comes from the circadian distribution of on-duty CHD deaths in firefighters,71 which mirrors the distribution of emergency alarms and dispatches, as well as that of fire service trauma deaths. Rather than following the typical circadian pattern seen in the general population, 67% to 77% of on-duty CHD deaths among firefighters occur between noon and midnight as do most emergency operations (Fig. 4).71

Regarding the seasonal pattern of on-duty CHD deaths, there is a winter peak with a smaller secondary peak in summer (Fig. 5).114 Seasonal effects could not be explained by day-to-day temperature fluctuations in the single seasonal study reported to date. However, the smaller summer excess of mortality was mostly due to a higher number of fire suppression deaths, making additional heat stress one plausible hypothesis. The winter peak may be produced in part by typical chronobiological changes observed during colder weather months, including increases in plasma viscosity, serum lipids, coagulation factors, and blood pressure, all of which are prothrombotic.115,116 Second, surges in influenza and upper respiratory infections typically occur in the first quarter of the year and have been associated with spikes in CHD incidence.113

MANAGEMENT OF CVD RISK IN THE FIRE SERVICE

The prevention and management of CVD risk among firefighters should include pre-placement medical examinations and PAT for new recruits. Additionally, continuing members should have periodic medical exams, PAT fitness and wellness programs, and “return to work” or “fitness for duty” evaluations.

Pre-placement Medical Examinations

Pre-placement medical examinations should be a part of the hiring process to review baseline health status, identify those requiring additional medical testing to rule out conditions possibly affecting job performance, and exclude those who are unable to safely...
perform the essential job duties. The National Fire Protection Agency (NFPA) (a private entity, which cannot mandate standards, but convenes committees of national experts to create consensus standards) as well as various government agencies have promulgated standards for pre-placement medical exams. In general, these standards specify minimum examination components and medical conditions that either lead to exclusion from a fire department or lead to exclusion under various circumstances or degrees of severity. With respect to CVD risk factors, the pre-placement medical examination should ideally include an assessment of habits (eg, tobacco use, diet, sleep hygiene, and exercise), anthropometric measures (BMI, waist circumference, body composition, that is, body fat estimates), blood pressure, lipids and glucose, resting ECG, as well as an objective measure of cardiorespiratory fitness (ie, a treadmill, stair climbing, bicycle ergometer, or similar test).

**Physical Abilities Testing**

PAT is a type of “functional capacity testing” that attempts to simulate the physical requirements of essential firefighting duties. Generally, it must be completed according to a fixed protocol within specific time limits on a standardized course or environment. The candidate PAT, which is endorsed by major Fire Service organizations, has been reported to elicit approximately 73% of maximal oxygen uptake and 90% of maximal heart rate in a group of
Cardiovascular Disease in US Firefighters

FIGURE 5. Seasonal Distribution of US firefighters’ CHD deaths. Reprinted from Chronobiol Int.114

individuals who successfully completed the test within the allotted time, and who were thought to be representative of incumbent firefighters.119 These authors also reported that maximal aerobic power, body mass, and handgrip strength accounted for 67% of the variance in completion time on the candidate PAT, although they noted large individual variations in estimations of time to completion. Like the pre-placement examination, PAT components and requirements are usually predetermined by a governmental entity or recommended by private groups that have convened expert panels.120,121 It should be conducted on candidate firefighters and veteran firefighters who have successfully completed all required medical evaluations and do not possess exclusionary conditions. It should never be used in the absence of a fire department medical examination to determine medical clearance.71 Any doubts about a firefighter’s fitness to safely engage in a PAT should be ruled out by a medically supervised exercise test.

Fitness and Wellness Programs

Fitness and wellness programs provide the opportunity for a broad array of preventive strategies.122–129 These programs should focus on the triad of healthy diet, regular and frequent exercise, and good sleep hygiene. A comprehensive wellness program will also provide educational programs and employee assistance options. Robust evidence supports the benefits of diets lower in saturated fats, salt, and refined carbohydrates; and higher in unsaturated fats, fiber, and fruits. Several studies are underway to evaluate firefighters’ eating habits, barriers to healthier diet options, and ways to improve or improveing the metabolic syndrome and lowering stress levels especially when coupled with healthy diets. Promoting improved gains in health and fitness may be realized from exercise programs, firefighters are overweight and one-third to 40% are obese, large in health and fitness may be realized from exercise programs, especially when coupled with healthy diets. Promoting improved sleep hygiene can have complimentary beneficial effects in preventing or improving the metabolic syndrome and lowering stress levels among firefighters. Additionally, normal sleep duration (7–8 hours per night) is associated with a lower incidence of obesity, diabetes, hypertension, myocardial infarction, stroke, and all-cause mortality when compared with so-called short sleep or chronic partial sleep deprivation (sleeping <-5–6 hours per night).130–134

Additional wellness measures should address tobacco use and influenza vaccination. Smoking or tobacco use should be prohibited among new hires and strong incentives along with specific programs on smoking cessation should be offered to incumbent firefighters who continue to smoke. Given firefighters’ close contact with the public while providing emergency medical services and that a relative excess of CHD deaths among firefighters occurs during the winter, annual influenza vaccinations should be strongly encouraged.

The firefighter wellness intervention trial called PHLAME (Promoting Healthy Lifestyles: Alternative Models’ Effects) is a prospective randomized controlled study that has examined both individual (one-on-one motivational counseling) and team approaches to health promotion. Both individual- and team-based interventions had positive effects on LDL cholesterol reduction and personal exercise habits, compared with controls.135 Additionally, at 1 year, both interventional groups improved weight control, significantly increased fruit and vegetable consumption and had a greater sense of well-being compared with controls.136 Although follow-up at 4 years showed some dissipation of the effects of the year-long interventions, dietary and exercise behaviors remained improved, on the whole, compared with baseline.137 Interestingly, even control groups showed improved health and dietary behaviors at follow-up, suggesting the dissemination of information on healthy behaviors from firefighters in the experimental groups to colleagues in the control groups.

Periodic Medical Examinations

Periodic medical examinations objectively assess risk factor profiles and are likely to identify firefighters in need of risk reduction before overt problems occur. Periodic examinations can also recognize firefighters who may need additional medical testing and may identify firefighters unable to safely perform the essential job duties of a firefighter so that they can be restricted from strenuous duties. Again, standards for such examinations have been recommended by the NFPA and government agencies in certain jurisdictions; and components should be similar to those of pre-placement examinations.

The sections above illustrate that hypertension, obesity, and dyslipidemia are inadequately managed among firefighters in the sense that large proportions of firefighters have risk-factor measurements that fall outside of evidence-based healthy and/or target ranges. Given firefighters’ occupational hazards for CVD, physicians should be more proactive when providing care to firefighters. It is also important to emphasize that periodical medical evaluations be provided to both career and volunteer firefighters.

Lipids

In general, lipids should be managed according to ATP criteria.138 No evidence from firefighters or similar occupational groups directly support high sensitivity C-reactive protein as a necessary adjunct to serum lipids in periodic exams, however, data from middle-aged and older adults in the general public suggest that it could be useful in identifying additional firefighters who despite low LDL values may benefit from primary prevention with statins.139,140

Blood Pressure

Blood pressure should be assessed and managed according to Joint National Committee guidelines.37,74 Unfortunately, the NFPA and some jurisdictions have suggested that blood pressures of up to 160 to 180/100 are acceptable for active duty.57,117,118 Outdated occupational blood pressure standards unintentionally encourage
firefighters to believe that elevated blood pressures are acceptable. Accordingly, a state of the art scheme for evaluating and managing emergency responders’ blood pressure within the Joint National Committee framework has been proposed (Table 4). Briefly, responders with stage 2 blood pressure (≥160/100 mm Hg) should be restricted from strenuous duties until better control is achieved and investigations for end-organ damage, including an echocardiogram to rule out left ventricular hypertrophy should be completed. Firefighters with stage 1 hypertension (140–159/90–99 mm Hg), should be given time-limited work clearances similar to corresponding rules for federally-regulated drivers, with work status and follow-up intervals depending on the achievement of improved blood pressure control at re-evaluation. Based on the chronicity of the elevated blood pressure in those with stage 1 hypertension and clinical judgment, an echocardiogram should be considered to evaluate possible left ventricular hypertrophy. Appropriate evaluations for left ventricular hypertrophy should also be done in firefighters with exaggerated blood pressure responses to exercise.

### Obesity

Despite the robust evidence of obesity’s negative effects, currently there are no occupational guidelines for obesity as a limiting condition for active duty among firefighters. Physicians should objectively assess weight status with BMI, waist circumference, and body fat measures. Because many firefighters have erroneous perceptions of their weight and have not been appropriately informed by physicians that they are carrying excess weight, overweight and obese firefighters should be given weight loss guidance based on exercise, diet, and sleep hygiene as first-line measures. Furthermore, we propose that firefighters with stage III obesity (BMI ≥40) be restricted from strenuous duty until they have lost weight and improved their fitness status.

### Aspirin

Following current guidelines, male firefighters aged >45 years should consider taking low dose acetylsalicylic acid (ie, 81 mg/d) as primary prevention. Aspirin has a strong antiplatelet effect under resting conditions, but does not attenuate increased platelet function occurring with exercise. Therefore, the preventive benefits of aspirin for firefighters are unknown. Studies in firefighters are underway to clarify the ability of acetylsalicylic acid to block several prothrombotic alterations in blood parameters that have been observed during acute firefighting activities.

### Exercise Testing

Further prognostic risk stratification of all asymptomatic firefighters without a history of atherosclerotic disease should include maximal exercise tolerance testing (ETT) starting at the age of 45 and earlier in firefighters with known CVD risk factors, depending on the risk profile. ETT results should be examined for electrocardiogram changes suggestive of ischemia, for blood pressure response, heart rate recovery, and exercise capacity. These results can then be interpreted using integrated risk tools such as the Duke treadmill score. We hypothesize that as in the general population, aerobic capacity or cardiorespiratory fitness will predict morbidity and mortality, with each additional MET achieved conveying additional benefit. The NFPA has suggested 12 METS as the minimum capacity required for safe firefighting. Prospective studies of asymptomatic firefighters are underway to better define ETT criteria.

If ETT are performed on asymptomatic individuals, most abnormal findings will ultimately be judged as “false positives.” Traditionally, firefighters with abnormal ETT have been evaluated further by myocardial perfusion imaging or stress echocardiograms. Roughly, 30% remain abnormal on the follow-up test and require invasive angiography, but only 26% of abnormal perfusion studies (8% of all abnormal ETTs) have angiogram findings of ≥50% stenosis of a coronary artery. In the Los Angeles County Fire Department, a more cost-effective protocol has been developed using coronary artery calcium scores as a “gate-keeper” test for asymptomatic firefighters with abnormal maximal treadmill tests as defined as ≥1 mm of ST depression. This is followed by a noninvasive computed tomography (CT) angiogram as the next study for those with high calcium scores. Finally, invasive angiogram is recommended only for those with an abnormal CT angiogram, with ≥50% stenosis being confirmed 95% of the time. We do not recommend coronary artery calcium scores or CT angiograms as routine tests at this time for all firefighters, although some medical

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**TABLE 4. Blood Pressure Management Scheme for Emergency Responders**

<table>
<thead>
<tr>
<th>Blood Pressure</th>
<th>Fitness Determination</th>
<th>Recommended Intervention(s)</th>
<th>Occupational Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Unrestricted duty</td>
<td>Population-based wellness programs</td>
<td>12–24 mo based on overall CVD risk factor profile</td>
</tr>
<tr>
<td>Pre-hypertension</td>
<td>Unrestricted duty</td>
<td>Population-based wellness programs, Individual education</td>
<td>6–12 mo based on overall CVD risk factor profile</td>
</tr>
<tr>
<td>Stage 1 Hypertension</td>
<td>Time-limited clearance for duty</td>
<td>Population-based wellness programs, Individual education, Hypertension treatment &amp; evaluation, including appropriate tests to rule out end-organ damage</td>
<td>Time-limited clearance (6–12 mo) based on overall CVD risk factor profile</td>
</tr>
<tr>
<td>Stage 2 Hypertension</td>
<td>Restricted to modified duty (excluding physical exertion related duties) until blood pressure reaches Stage 1 or lower</td>
<td>Population-based wellness programs, Individual education, Clinical management of Hypertension and evaluations for end-organ damage, including echocardiogram</td>
<td>Time-limited clearance after adequate blood pressure control, revert to annual follow-up</td>
</tr>
</tbody>
</table>

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* Assumes absence of comorbid conditions potentially affecting fitness for duty, prognosis, and treatment decisions.

† Adapted from Ann J Hypertens.

‡ Full CVD risk factor assessment, including tobacco use, fasting lipid profile, blood glucose level, etc.

§ DASH: Dietary Approaches to Stop Hypertension, and other non-pharmacologic measures.

CVD indicates cardiovascular disease.
centers are promoting and marketing these tests as “screens” to the fire service.

**Fitness for Duty /Return to Work Evaluations**

Fitness for duty or return to work evaluations are extremely useful in the risk assessment and characterization of firefighters who have developed overt CVD, and may no longer qualify for strenuous activities. Because many fire departments do not permit modified duty, physicians should verify with the fire department any claims by firefighters that their duties are not strenuous or somehow are limited to certain activities. On the basis of overwhelming evidence supporting higher relative risks of on-duty death and disability among firefighters with a history of CHD (Table 2), most firefighters with known CHD or CHD equivalents (previous thrombotic strokes, transient ischemic attacks, carotid stenosis, or symptomatic peripheral arterial disease) should be restricted from participating in strenuous emergency duties. Current evidence suggests that if firefighters with known clinically significant atherosclerotic disease were restricted from emergencies, such a measure would likely lead to a decrease of about 30% in on-duty CV mortality in the fire service, given that these cases currently account for 31% of on-duty fatalities. However, certain select individuals who are asymptomatic, have excellent exercise capacity, no myocardial damage, and are found with very early evidence of CHD as a result of screening may be able to safely continue performing firefighting duty. The NFPA has suggested criteria for evaluating safe return to work in the presence of CHD (Table 5). However, their criteria have not been validated by prospective or retrospective studies, and clinicians should bear in mind that prior atherosclerotic disease independently predicted case-fatality, and that death was more common in those who had returned to service with prior evidence of myocardial damage from earlier infarction(s).

**MEDICOLEGAL ISSUES**

Because firefighters are generally government employees and provide public services, CVD among firefighters represents an important public health/policy problem with death, disability, and retirement benefits typically regulated by specific legislation. In particular, special legislative provisions often legally “presume” CVD among firefighters to be work-related regardless of the presence of standard CVD risk factors. More than 35 states have “presumptive” laws entitling firefighters with HD to receive publicly funded disability and/or death benefits. In general, this type of benefit legislation creates the legal presumption that the firefighters’ disease is causally related to firefighting even in the presence of other obvious disease risk factors. The Hometown Heroes Survivor Benefits Act provides federal aid to the families of firefighters, police officers, and EMS workers who die of on-duty heart attacks or stroke. Given that society has decided to fund such benefits, both the fire service and taxpayers would be better served if a portion of these resources were invested proactively in prevention programs to reduce firefighters’ CVD morbidity and mortality, as well as generate downstream cost-savings. This recommendation is especially important given that resources devoted to prevention programs for many fire departments are either nonexistent or scarce at best.

In jurisdictions lacking strong legal presumptions, several studies (Table 3) provide a stronger basis for making determinations of work-relatedness. The findings in Table 3 support previous suggestions by Guidotti that events occurring during or within a day of strenuous duties, such as fighting a fire, responding to or

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**TABLE 5.** NFPA Guidelines for Veteran Firefighters for Return to Work in the Presence of CHD

| No angina  |
| No stenosis of major coronary artery (>70% of lumen) |
| Normal LVEF |
| Exercise tolerance >12 METS during EST |
| No exercise induced angina |
| No ischemia or arrhythmias during EST (with imaging) |
| No persistence of modifiable risk factor for plaque rupture (tobacco, HBP, cholesterol >180, LDL >100, HbA1c >7) |


CHD indicates coronary heart disease; LVEF, left ventricular ejection fraction; METS, metabolic equivalents; EST, exercise stress test; HBP, high blood pressure; LDL, low density lipoprotein; HbA1c, glycated hemoglobin.

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**FIGURE 6.** Theoretical model of atherosclerosis and possible adverse health outcomes in firefighters.

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returning from an alarm, or involving vigorous physical training or a strenuous rescue, are likely to be work-precipitated.

CONCLUSIONS

In conclusion, CVD remains the leading cause of line of duty death among firefighters (45% of on-duty fatalities) and the prevalence of standard CVD risk factors remains high in this occupational group. Over the last decade, however, our understanding of CVD among firefighters has significantly improved with respect to the following. First, the physiology of CV arousal and other changes that occur in association with acute firefighting activities have been well-characterized. Second, unique statistical approaches have documented that on-duty CVD events do not occur at random in the fire service. They are more frequent at certain times of day, certain periods of the year, and are overwhelmingly more frequent during strenuous duties compared with nonemergency situations. Third, clinical epidemiology investigations have proven, as expected, on-duty CVD events occur almost exclusively among susceptible firefighters with underlying CVD (whether overt and previously diagnosed or not). Furthermore, all fire departments should have entry-level medical evaluations, institute periodic medical evaluations, and define return to work evaluations. Finally, adverse events while performing emergency duties. Furthermore, all fire departments should have entry-level medical evaluations, institute periodic medical evaluations, and define return to work evaluation procedures that require clearance by an experienced occupational physician after major or significant illness. On the basis of overwhelming evidence supporting markedly higher relative risks of on-duty death and disability among firefighters with a history of CHD, most firefighters with known CHD or other clinically significant atherosclerotic endpoints should be restricted from participating in strenuous emergency duties.

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