

The Relation of Emergency Duties to Cardiac Death Among US Firefighters



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Sudden cardiac death accounted for 42% of all firefighter duty-related fatalities over the last decade. This retrospective study analyzed available medical examiner records for duty-related firefighter fatalities among male firefighters 18 to 65 years of age that occurred between 1999 and 2014 and reported the pathoanatomic substrate for cardiac-related fatalities. Odds of duty-related cardiac death during specific duties compared with fire station duties were calculated by pathoanatomic substrate. There were 285 cardiac fatalities. Of fatalities, 80% had evidence at autopsy of coronary heart disease (CHD) and increased heart size (cardiomegaly and/or left ventricular hypertrophy). CHD alone, cardiomegaly or left ventricular hypertrophy, and causes other than CHD or increased heart size were identified in 7.7%, 6.0%, and 6.7% of fatalities, respectively. The largest proportion of deaths occurred during fire suppression (33%), although only 1% of annual occupational time was estimated to be spent performing this duty. For deaths attributed to CHD and increased heart size, fire suppression, alarm response, and physical training were associated with approximately a 112-fold, eightfold, and sevenfold increased risk of cardiac death, respectively, compared with station duties. In conclusion, the majority of firefighters who suffered a duty-related cardiac death had CHD and increased heart size, which was associated with a markedly increased risk of death during fire suppression compared with station duties. Targeted occupational medical screening for CHD and increased heart size may reduce duty-related cardiac deaths among firefighters. © 2019 Elsevier Inc. All rights reserved. (Am J Cardiol 2019;123:736–741)

Sudden cardiac death (SCD) is consistently the leading cause of on-duty firefighter fatalities, accounting for approximately 42% of these fatalities annually.¹ Fire suppression and emergency duties are associated with a markedly higher risk of death from coronary heart disease (CHD) compared with nonemergency duties.^{2,3} Researchers have documented cardiovascular responses to firefighting,^{4–7} described job-related factors that increase cardiovascular strain,^{8–10}

identified cardiovascular disease risk factors and underlying conditions that increase the risk of cardiac death among firefighters,^{3,11–13} and proposed models that depict how the cardiovascular strain of firefighting may trigger a sudden cardiac event in a susceptible firefighter.^{8,9,14} However, little work has focused on the link between job-related stressors and underlying cardiovascular pathology. SCD has long been associated with underlying CHD^{2,3,11,15–17}; however, there is increasing evidence that cardiac enlargement (cardiomegaly and left ventricular hypertrophy [LVH]) also plays an important role in sudden cardiac events.^{12,13,18–21} Therefore, this study identified the pathoanatomic substrate in cases of duty-related death attributed to underlying cardiac disease and explored its association with the type of firefighting duty last performed.

Methods

This retrospective study relied on autopsy and/or medical examiner report data from a national database to explore the pathoanatomic substrate of all firefighters who died in the line of duty between 1999 and 2014. The Skidmore College Institutional Review Board determined that the use of records from deceased subjects did not meet the definition of human subject research and granted the study an exemption.

The US Fire Administration (USFA) defines an on-duty fatality as any injury or illness sustained while on-duty that proves fatal, including a sudden cardiac event or stroke within 24 hours of a training activity or emergency

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response. The National Institute for Occupational Safety and Health (NIOSH) reviews a portion of firefighter duty-related fatalities and the resulting reports are made publicly available online. All relevant corresponding NIOSH fatality reports were also obtained.

Fire service authorities categorize cause of death as being due to general medical causes, including heart attack (cardiac), cerebrovascular, trauma, burns, and asphyxiation, for all fatalities. Two investigators verified cause of death for each fatality and classified the fatal injury as being due to a cardiac, trauma, other vascular, or indeterminate cause of death. Inclusion criteria for the present study were as follows: (1) firefighter duty-related fatality between 1999 and 2014, (2) autopsy-verified cardiac cause of death, (3) male sex, and (4) age between 18 and 65 years. Women were excluded from the analyses due to the low number of female firefighters ($n=4$) among cardiac deaths and age was restricted to 18 to 65 years as age restrictions are frequently in place for career firefighters.

Two reviewers extracted cardiac findings from each cardiac case and a senior investigator (DLS or SNK) resolved any disagreements between the reviewers. Age and sex were taken from the medical examiner's report. Body mass index (BMI) was calculated as body mass in kilograms divided by the square of height in meters using measurements recorded at autopsy. In cases when autopsy height or body mass was deemed inaccurate due to factors such as severe damage to the corpse, multiple organ procurement, or inclusion of firefighting gear in body mass, a BMI was not calculated; however, a BMI value from a NIOSH report was used if available.

Cardiac deaths were categorized based on pathoanatomic substrates identified at autopsy: CHD, increased heart size (cardiomegaly and/or LVH), CHD and cardiomegaly and/or LVH, and Other. CHD was considered present if it was noted in the autopsy narrative report or if the percentage of stenosis in at least 1 coronary artery was reported as $\geq 75\%$. A structurally enlarged heart was considered present if it was noted in the autopsy narrative report, or if the heart weight was reported as >450 g, or if the left ventricular wall thickness was reported as ≥ 1.2 cm. A combination of both CHD and structurally enlarged heart was considered present if the aforementioned criteria for both were met. The Other category included deaths where the presumed primary underlying cause was not in the previous categories, including Wolff-Parkinson-White syndrome, pericardial tamponade, and any valvular heart disease.

The type of duty performed when the onset of symptoms occurred was obtained from data provided by the USFA. We relied on the USFA definitions of type of duty,²² except that we defined classroom training as a nonemergency and/or routine duty rather than as physical training, described in the following:

- (1) Alarm response—all events occurring after an emergency dispatch and before reaching the scene;
- (2) Fire suppression—all operational activities on the fire-ground (scene of a fire);
- (3) Emergency Medical Services (EMS) and other nonfire emergencies—all operational activities at nonfire

emergency incidents, such as EMS, rescues, and motor vehicle accidents;

- (4) Alarm return—all events occurring during the return from an emergency incident and concluding upon arrival back at the station or other intended destination (e.g., home or job site);
- (5) Physical training—any job-related physical fitness training, physical abilities testing, and/or hands-on firefighting training;
- (6) Fire station and other nonemergency duties—fire station tasks and nonemergency duties (e.g., administrative, maintenance, inspection, classes and/or seminars and/or meetings).
- (7) Other—within 24 hours of strenuous activity with no symptoms reported.

Categories 1 to 6 are based on when the cardiac event occurred or when symptoms were first reported during the on-duty shift. Category 7 is inclusive of events that occurred within 24 hours of strenuous activity when no symptoms were reported before going off-duty and is included to account for legislation that expanded the definition of on-duty fatality.

A national estimate of the annual proportion of time spent in each type of fire service duty has been developed from nationwide National Fire Protection Association surveys and used in several published studies.^{2,23} The "national estimate" was used to estimate the expected number of cardiac deaths during specific emergency duties, physical training, or station and other nonemergency duties.

We assumed that if there is no association between the amount of time spent on a specific duty and the risk of cardiac death then the proportion of deaths under each duty would be directly proportional to the time spent in that duty. We calculated the ratio of actual (observed) cardiac deaths and expected deaths as estimated using the national average for each specific duty and we further computed 95% confidence intervals (CIs) for these ratios on the basis of the multinomial distribution. Based on these odds and using fire station and other nonemergency duties as the reference group, we also estimated the odds ratios (ORs) for cardiac death under each specific duty and the accompanying 95% CIs were calculated with the use of the binomial distribution. The Fisher's exact test was used to test for an association between the pathoanatomic cause of death and firefighting duty. Statistical analysis was performed with the use of SAS 9.3 (SAS Institute Inc., Cary, NC) and all tests reported are 2-sided with statistical significance defined as a p value <0.05 .

Results

Figure 1 presents the process for identifying the study population and the pathoanatomic substrate for on-duty cardiac-related deaths among firefighters in the study period 1999 to 2014. Of the 1,644 duty-related fatalities identified, autopsies and/or medical reports were available for roughly half (851), and 285 met the study criteria for inclusion as duty-related cardiac death. On average, cardiac fatalities in the study population were 49 ± 9 years of age, had a BMI of 31.8 ± 5.8 kg/m², and had served 19 ± 12 years in the fire service at the time of death. Based on study criteria, the

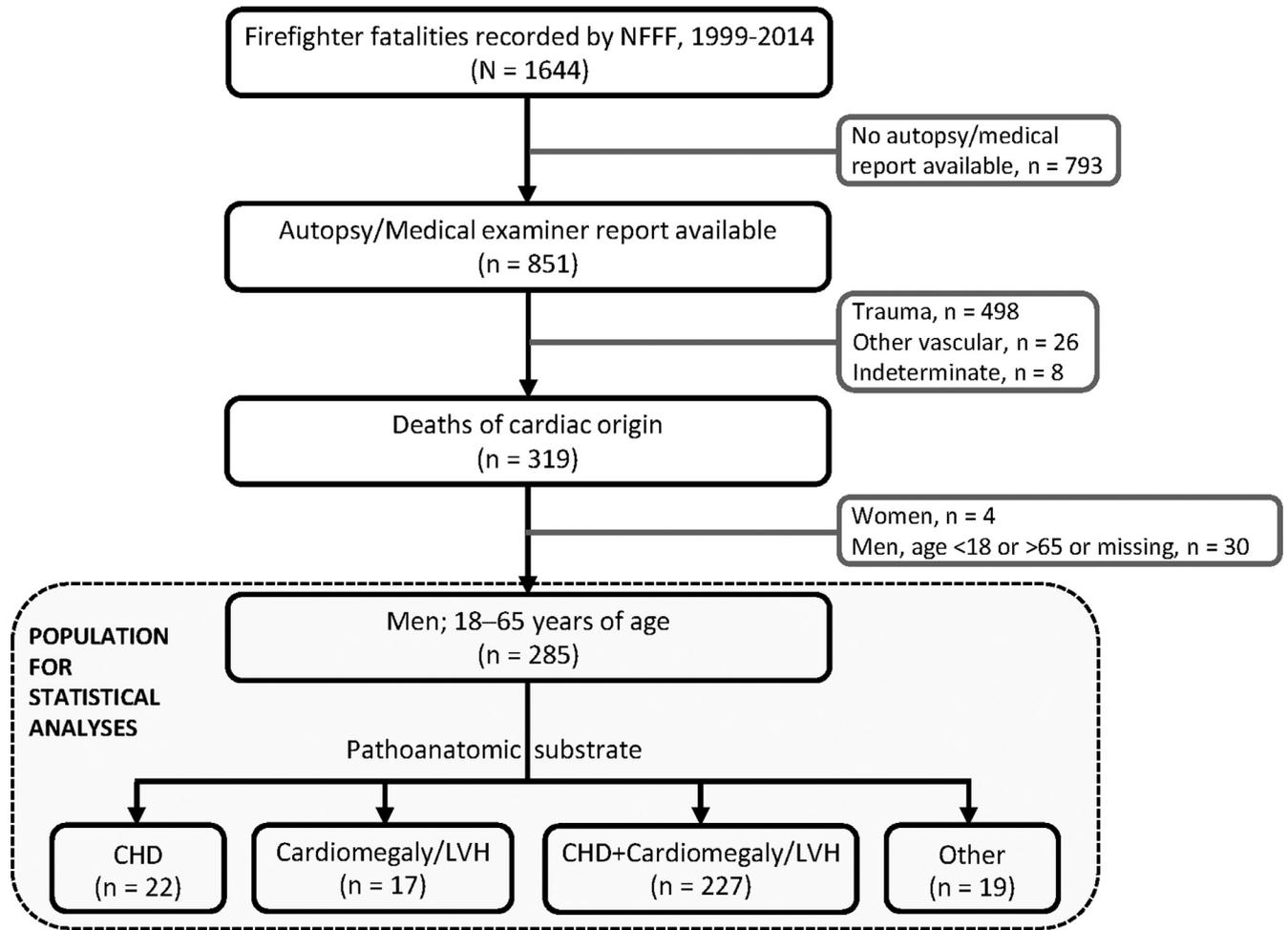


Figure 1. Process for identifying population used for statistical analyses—on-duty, male, career, or volunteer US firefighters between 18 and 65 years of age with underlying pathoanatomic substrate determined to be cardiac in origin by autopsy or medical records. CHD = coronary heart disease; LVH = left ventricular hypertrophy; NFFF = National Fallen Firefighters Foundation.

vast majority of these cardiac fatalities (79.6%) had evidence at autopsy of CHD and cardiomegaly and/or LVH. Only 7.7% firefighters had CHD alone and 6.0% had cardiomegaly and/or LVH exclusively.

Table 1 lists the number and proportion of observed cardiac deaths according to the type of duty at the time of the

observed or reported onset of symptoms and the OR (risk) of duty-related death based on national estimates of time spent annually in each activity. A cardiac death was 87 (95% CI 59, 127) times more likely to occur during fire suppression activity than fire station or other nonemergency duties. Statistically elevated odds of cardiac death were

Table 1

Risk of cardiac duty-related death among US firefighters engaged in emergency duties and physical training compared with firefighters engaged in nonemergency duties based on national data estimates of time spent in specific firefighting duties

| Firefighting duty | Observed deaths (n = 208) | Time spent annually | Expected deaths | | | |
|---|------------------------------|------------------------|-----------------|-------------------|--------------------|---------|
| | | | E | O/E (95% CI) | OR (95% CI) | p value |
| Alarm response | 22 (10.6%) | 4% | 8.3 | 2.64 (1.52, 4.46) | 7.0 (4.0, 11.8) | <0.001 |
| Fire suppression | 68 (32.7%) | 1% | 2.1 | 32.7 (24.6, 42.0) | 86.7 (59.4, 127.1) | <0.001 |
| Alarm return | 8 (3.9%) | 7% | 14.6 | 0.55 (0.20, 1.29) | 1.5 (0.6, 3.1) | 0.42 |
| EMS and other non-fire emergencies | 18 (8.6%) | 15% | 31.2 | 0.58 (0.30, 1.03) | 1.5 (0.8, 2.7) | 0.17 |
| Physical training | 41 (19.7%) | 8% | 16.6 | 2.46 (1.49, 3.32) | 6.5 (4.2, 10.1) | <0.001 |
| Fire station and other non-emergency duties | 51 (24.5%) | 65% | 135.2 | 0.38 (0.26, 0.51) | 1.00 (ref.) | - |

CI = confidence interval; E = expected deaths based on national estimates of time spent annually performing the specific duty; O/E = value of observed deaths/expected deaths; OR = odds ratio.

For observed deaths, values are presented as number (%).

Table 2
Distribution of pathoanatomic substrate by type of duty

| Firefighting duty | CHD (n = 16) | Cardiomegaly/LVH (n = 15) | CHD + cardiomegaly/LVH (n = 165) | Other (n = 12) |
|--|--------------|---------------------------|----------------------------------|----------------|
| Alarm response (n = 22) | 2 (9.1%) | 3 (13.6%) | 17 (77.3%) | 0 (0.0%) |
| Fire suppression (n = 68) | 3 (4.4%) | 2 (2.9%) | 62 (91.2%) | 1 (1.5%) |
| Alarm return (n = 8) | 2 (25.0%) | 0 (0.0%) | 6 (75.0%) | 0 (0.0%) |
| EMS and other non-fire emergencies (n = 18) | 1 (5.6%) | 2 (11.1%) | 15 (83.3%) | 0 (0.0%) |
| Physical training (n = 41) | 5 (12.2%) | 2 (4.9%) | 29 (70.7%) | 5 (12.2%) |
| Fire station and other non-emergency duties (n = 51) | 3 (5.8%) | 6 (11.8%) | 36 (70.6%) | 6 (11.8%) |

CHD = coronary heart disease; LVH = left ventricular hypertrophy. Values are reported as number (%), where % represents percentage within type of duty. CHD defined as noted on autopsy or coronary artery stenosis ≥75%. Cardiomegaly/LVH defined as noted on autopsy or heart weight >450 g or left ventricular wall thickness ≥1.2 cm.

also found for alarm response and physical training compared with fire station or other nonemergency duties. There were 77 cardiac fatalities classified as Other that occurred within 24 hours of strenuous duty with no symptoms reported on shift, thus, they did not fit into the categories defined in the table and are not shown.

The proportion of cardiac deaths by pathoanatomic substrate and firefighting duty are presented in Table 2. Seventy-nine percent (165 of 208) of cardiac fatalities had underlying CHD and cardiomegaly and/or LVH. A significant association between type of duty and pathoanatomic substrate was found (p = 0.047). The largest share (33%) of deaths occurred during fire suppression, and 91% of those fatalities had evidence of CHD and structurally enlarged heart.

Among the 77 fatalities that were classified as occurring “within 24 hours of strenuous duty with no symptoms reported,” 81% of fatalities occurred in firefighters with CHD and cardiomegaly and/or LVH compared with 8% for CHD, 3% for structurally enlarged heart, and 9% for other underlying causes of cardiac death (data not shown). Fire-ground operations, EMS and other nonfire emergency operations, and physical training were the last types of stressful and/or strenuous activity reported for 47%, 33%, and 13% of cases, respectively (data not shown).

Table 3 lists the risk of duty-related cardiac death by pathoanatomic substrate. Among fatalities with both CHD and structurally enlarged heart, the odds of cardiac death were increased during fire suppression, alarm response, and physical training compared with station duties. In comparison, elevated odds of cardiac death compared with station duties were found during fire suppression and alarm response among fatalities with cardiomegaly and/or LVH

| Firefighting duty | Coronary heart disease (n = 16) | | | | Cardiomegaly/LVH (n = 15) | | | | CHD + cardiomegaly/LVH (n = 165) | | | | Other (n = 12) | | | | | | | | |
|--|---------------------------------|------|-------|-------------------|---------------------------|-----|------|-------|----------------------------------|---------|-----|--------|----------------|-----------------|---------|-----|------|------|-------------------|---------|------|
| | Obs | Exp | O/E | OR (95% CI) | p value | Obs | Exp | O/E | OR (95% CI) | p value | Obs | Exp | O/E | OR (95% CI) | p value | Obs | Exp | O/E | OR (95% CI) | p value | |
| Alarm response (n = 22) | 2 | 0.64 | 3.13 | 10.8 (0.90, 94.6) | 0.06 | 3 | 0.60 | 5.00 | 8.1 (1.3, 38.0) | 0.025 | 17 | 6.60 | 2.58 | 7.7 (4.0, 14.0) | <.001 | 0 | 0.48 | 0.0 | 0.0 | 0.0 | - |
| Fire suppression (n = 68) | 3 | 0.16 | 18.75 | 65.0 (8.7, 485) | <.001 | 2 | 0.15 | 13.33 | 21.7 (2.1, 121) | 0.012 | 62 | 1.65 | 37.58 | 112 (73.1, 174) | <.001 | 1 | 0.12 | 8.33 | 10.8 (0.23, 89.3) | 0.20 | 0.20 |
| Alarm return (n = 8) | 2 | 1.12 | 1.79 | 6.2 (0.52, 54.1) | 0.15 | 0 | 1.05 | 0.0 | 0.0 | - | 6 | 11.55 | 0.52 | 1.5 (0.53, 3.7) | 0.44 | 0 | 0.84 | 0.0 | 0.0 | - | |
| EMS and other non-fire emergencies (n = 18) | 1 | 2.40 | 0.42 | 1.4 (0.03, 18.0) | 1.0 | 2 | 2.25 | 0.89 | 1.4 (0.14, 8.1) | 0.92 | 15 | 24.75 | 0.61 | 1.8 (0.92, 3.4) | 0.09 | 0 | 1.80 | 0.0 | 0.0 | - | |
| Physical training (n = 41) | 5 | 1.28 | 3.91 | 13.5 (2.6, 87.2) | 0.001 | 2 | 1.20 | 1.67 | 2.7 (0.27, 15.2) | 0.43 | 29 | 13.20 | 2.20 | 6.5 (3.9, 11.0) | <.001 | 5 | 0.96 | 5.21 | 6.8 (1.6, 26.6) | 0.008 | |
| Fire station and other non-emergency duties (n = 51) | 3 | 10.4 | 0.29 | 1.0 | - | 6 | 9.75 | 0.62 | 1.0 | - | 36 | 107.25 | 0.34 | 1.0 | - | 6 | 7.80 | 0.77 | 1.0 | - | |

CHD = coronary heart disease; CI = confidence interval; Exp = expected deaths based on national estimates of time spent annually performing the specific duty; LVH = left ventricular hypertrophy; Obs = observed deaths; O/E = value of observed deaths/expected deaths; OR = odds ratio. CHD defined as noted on autopsy or coronary artery stenosis ≥75%. Cardiomegaly/LVH defined as noted on autopsy or heart weight >450 g or left ventricular wall thickness ≥1.2 cm.

alone and during fire suppression and physical training among fatalities with CHD alone. The small sample sizes for CHD, cardiomegaly and/or LVH, and other causes of death led to estimates that were relatively unstable as reflected by the wide CIs for some duties.

Discussion

This study systematically categorized duty-related cardiac fatalities based on pathoanatomic substrate reported in autopsies (1999 to 2014) among a large nationally representative sample of male US firefighters (18 to 65 years of age). The major finding of this study was that 80% of duty-related cardiac fatalities had evidence of both CHD and cardiomegaly and/or LVH, only 8% of fatalities had evidence of CHD alone, and another 6% had evidence of cardiomegaly and/or LVH without CHD. Thus, we extended previous research that identified a high prevalence of cardiomegaly¹² or LVH^{3,11} among CHD or SCD fatalities among firefighters. We further extended findings by investigating the duty-specific risk of cardiac death by pathoanatomic substrate and found that the odds of cardiac-related death during or after fire suppression were 112 times greater than during fire station duties in firefighters who had both CHD and cardiomegaly and/or LVH.

Consistent with previous studies,^{2,3,23} we found that fire suppression conveyed, by far, the greatest risk of cardiac death, with odds of cardiac death nearly 90 times greater during fire suppression than during fire station and nonemergency duties. In contrast to previous studies,^{2,23} alarm return was not associated with an increased risk of duty-related cardiac death because this study relied on the USFA definitions of type of duty, where alarm return concluded upon arrival back at the station or other intended destination. Previous studies considered all events that occurred upon returning from an emergency²³ or within several hours after an emergency call² as occurring during alarm return.

The study is the first to investigate the premise that the risk of cardiac death during firefighting duties could differ based on the underlying anatomic and/or functional substrate. Strenuous and/or stressful firefighting activities are associated with several factors known to be triggers (transient events) of SCD. Strenuous physical activity, particularly in subjects who are unaccustomed to the activity; environmental exposures, such as particulate matter in smoke; and psychological stress are all potential triggers of acute cardiovascular events.²⁴ The effect of a trigger depends on the magnitude of disruption and the susceptibility of the underlying anatomic and functional substrates, with the latter depending, in part, on the mechanism of the trigger.

We found that among firefighter fatalities with CHD and cardiomegaly and/or LVH, the risk of cardiac death associated with fire suppression was approximately 110 times greater than during fire station duties. The extremely high odds of cardiac death during fire suppression can likely be attributed to extensive physiological disruptions and the increased susceptibility to myocardial infarction or arrhythmia with both CHD and cardiomegaly as underlying substrates.

Patients with cardiomegaly and/or LVH, either alone or in combination with CHD, had a significantly elevated risk of cardiac death during alarm response. It may be the

sympathetic surge during an alarm response is sufficient to trigger cardiac death in these patients because hypertrophied myocardium is an arrhythmogenic substrate, which may predispose to ischemia.

This study is the first to classify the “Other - within 24 hours of strenuous duty with no symptoms reported” (“after strenuous duty”) separately. The inclusion of this category arose following the Hometown Heroes Survivors Benefit Act of 2003, which considered any cardiovascular event that occurred after going off-duty and within 24 hours of engaging in nonroutine stressful or strenuous activity as occurring in the line of duty. The finding of a high percentage of cardiac death occurring “after strenuous duty,” may reflect, in part, the prolonged disruption to the cardiovascular system that occurs with the combination of strenuous activity and physiologically stressful work.

The main strength of this study is the use of autopsy records to identify the underlying pathoanatomic substrate in duty-related cardiac deaths. Previous studies have primarily relied on data from NIOSH investigations, which are not representative of all deaths, or short summaries provided by the USFA. Additionally, we used a more expansive definition of duty-related fatality than has been used in previous firefighter fatality studies. The study also has some limitations. The use of national estimates of annual time spent in different duties to estimate the odds of cardiac death during a specific firefighting duty represents only 1 exposure scenario. The small sample sizes of the CHD, cardiomegaly and/or LVH, and Other groups resulted in ORs that were relatively unstable, thus limiting statistical interpretability of results.

Known triggers of SCD are inherent to the job of firefighting; therefore, to achieve the goal of decreasing SCD among firefighters, the most pragmatic approach is to identify firefighters with an underlying pathoanatomic substrate that increases the risk of SCD. Current fire service medical screening guidelines are focused heavily on CHD; however, our results emphasize that it is appropriate to screen for evidence of both CHD and cardiomegaly and/or LVH in firefighters. Clearly, there are multiple physiological connections between CHD and cardiomegaly and/or LVH; thus, major prevention strategies are likely to be similar.^{10,14}

Disclosures

Dr. Kales reports serving as a paid expert witness, an independent medical examiner, or both in workers' compensation and disability cases, including cases involving firefighters. Dr. Smith reports serving as a consultant in cases involving medical evaluations and firefighter fatalities.

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