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Findings and Recommendations from Non-Invasive Identification of Left Ventricular Hypertrophy/ Cardiomegaly in Firefighters

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Contents

List of Acronyms

BMI	Body Mass Index
CHD	Coronary Heart Disease
CVD	Cardiovascular Disease
LV	Left ventricular
LVH	Left Ventricular Hypertrophy
LVM	Left Ventricular Mass
SCD	Sudden Cardiac Death
ECHO	Echocardiography
CMR	Cardiac Magnetic Resonance
CRF	Cardiorespiratory Fitness
OSA	Obstructive Sleep Apnea

Glossary of Terms

Arrhythmia – irregular heart beat.

Body Surface Area – a measure that reflects that total skin surface area of the human body.

Cardiomegaly – a general term used to describe an enlarged heart; can be caused by various conditions, but often associated with hypertension and coronary artery disease.

Cardiovascular Disease (CVD) – refers to diseases or problems of the heart and/or blood vessels.

Cardiovascular strain – refers to the physiological response of the cardiovascular system to exercise or physical work.

Coronary Heart Disease (CHD) – a narrowing of the blood vessels (coronary arteries) that supply blood and oxygen to the heart tissue; often called coronary artery disease (CAD).

Heart attack – also known as myocardial infarction; occurs when heart's blood supply vessels (coronary arteries) is insu□cient preventing the blood supply from reaching the heart.

Left ventricular – largest chamber of the heart responsible for pumping blood out to the brain, other vital organs and the rest of the body.

Left ventricular hypertrophy – a thickening of the heart muscle surrounding the left ventricle, resulting in a greater mass of the heart.

Left ventricular mass index – a measure of left ventricular weight adjusted for body size that derived by dividing LV mass by some a body size parameter (e.g. body surface area, height) to account for physiologic variation related to body size.

Prevalence – a measure to reflect the proportion of a population who has (or had) a specific characteristic in a given time period.

Sudden cardiac death – an unexpected cardiovascular death due to heart attack or arrhythmia, where loss of consciousness occurs abruptly after the onset of symptoms or without warning and death quickly ensues thereafter.

Sudden cardiac event – an unexpected cardiovascular event (stroke, heart attack, heart arrhythmia) that occurs suddenly in a person with or without diagnosed cardiovascular disease. This event may or

Purpose and Objectives

This white paper presents attainable and practical approaches to improve firefighter health and safety targeted to fire service leadership and individual firefighters. This is accomplished through the specific objectives identified below.

Objectives

1. To raise awareness within the fire service about enlargement of the heart (including cardiomegaly and left ventricular (LV) hypertrophy) and how it increases the risk of developing CVD and on-duty SCD; as well as it's potential to be treated and reversed if recognized beforehand.

2. To summarize the current challenges we face in the identification of cardiac enlargement in active firefighters according to the method of

Executive Summary

This white paper is based on the background, key findings and recommendations of work sponsored by FEMA (US Department of Homeland Security) to better understand cardiac enlargement in the US fire service. Roughly half (45%) of the nation's line-of-duty firefighter fatalities are due to cardiovascular disease (CVD), and about 45% are due to sudden cardiac death (SCD). These events almost always occur in susceptible individuals with underlying heart problems. Unfortunately, many of these heart problems are not recognized during firefighters' careers or go untreated, and this is particularly true of cardiac enlargement. Firefighter autopsy reports demonstrate that a large majority of firefighters succumbing to SCD had significant narrowing of one or more coronary arteries, consistent with coronary heart disease (CHD), which has been the focus of most CVD research in the fire service. Although less well-known, previous research has also shown that a majority of firefighters dying of SCD have had various forms of cardiac enlargement- usually accompanying CHD, but sometimes as the only or predominant heart abnormality.

Cardiomegaly refers to enlargement of the heart in general as well as to an abnormally heavy heart by weight. **Left ventricular (LV) hypertrophy** is a related term that specifically refers to enlargement (measured either as increased wall thickness or elevated weight) of the left ventricle - the chamber of the heart responsible for pumping blood out to the circulation and vital organs. Both LV hypertrophy and cardiomegaly are frequently found during the autopsies of persons who died of SCD. LV hypertrophy/cardiomegaly are structural abnormalities of the heart proven to increase the risk of arrhythmias, myocardial infarction, stroke and the risk of death. Cardiac enlargement is a condition, which renders firefighters susceptible to cardiovascular events up to and including SCD.

Despite the longstanding issue of CVD deaths in the fire service and the frequent observation of LV hypertrophy/cardiomegaly in autopsies, very little is known about these conditions in active firefighters. For example, how common is heart enlargement among working firefighters, what are the best methods of measuring its presence, and which firefighters are at highest risk and therefore, should be screened. It is important to note that if recognized beforehand, e□ective treatments for LV hypertrophy/ cardiomegaly are available. Thus, it is imperative that we find e□ective ways to screen firefighters at risk for this condition.

This white paper presents the current challenges that we face in accurately defining cardiac enlargement, provides more definitive estimates of how common it is among active career firefighters, and identifies the most important predictors of cardiac enlargement. Lastly, specific recommendations targeted to di□erent important stakeholders are presented in order to decrease the burdens of CVD and SCD in the fire service.

Firefighters from the Indianapolis Fire Department worked together with research scientists, medical doctors and along with local and national fire service leaders in order to make this project a suc-

cess. In this report we provide details on a series of studies we conducted so as to describe how common cardiac enlargement is, in a 400 group of occupationally active career firefighters (from the Indianapolis Fire Department) using di□erent imaging techniques and among a group of 353 fallen firefighters from all across the US who su□ered on-duty fatalities due to a traumatic, non-cardiac cause, using autopsy data. In both groups of firefighters we investigated the presence of cardiac enlargement and its relationship to to various medical and other factors.

Even though standardization of cardiac enlargement definitions is needed, **our results clearly demonstrate that obesity as measured by body mass index (BMI) drives LV mass, heart weight and LV wall thickness. Therefore, reducing obesity will decrease LV mass, improve CVD risk profiles, and should in turn reduce on-duty CVD events in the fire service, including SCD.**

Our understanding of sudden cardiac events and cardiovascular disease in the fire service has greatly and rapidly increased over the past 15 years due to a shared sense of mission in reducing duty-related cardiac deaths by researchers, fire service representatives, and funding agencies. **But, knowledge alone cannot bring about the needed results. Action is required— recommendations must be actionable, then, adopted and finally, implemented. Adoption of the actionable, evidence-based recommendations in this and previous reports will help the US fire service make significant strides toward reducing duty-related cardiac deaths, with a reduction of at least 30% within reach.**

BMI drives heart weight, left ventricular mass and wall thickness.

Background

Cardiovascular disease (CVD) is the leading cause of on-duty death among US firefighters and an important and costly cause of morbidity. CVD causes about 50% of firefighters' on-duty deaths and,

Enlargement of the heart is considered a structural abnormality of the heart[17,18] and appears to be a key pen-ultimate and predisposing step on the causal pathway that makes a firefighter susceptible to CVD events (Figure 1- orange star). [1,19,20] Cardiomegaly refers to enlargement of the heart in general as well as to an abnormally heavy heart by weight. Most pathologists consider a heart weight above 450 g in a man and 390 g in a woman to be abnormally heavy or consistent with cardiomegaly. Left ventricular (LV) hypertrophy is a related term that specifically refers to enlargement of the left ventricle or the chamber of the heart responsible for pumping blood out to the circulation and vital organs. LV hypertrophy is usually defined as an increased thickness of the left ventricular wall as measured by a pathologist at autopsy or estimated by an imaging technique, or an elevated LV mass or weight of the left ventricle as measured by various imaging techniques. The two most frequently used non-invasive, imaging modalities for the assessment of LV wall and LV mass have been echocardiography (ECHO) and cardiac magnetic resonance (CMR). [21]

Defining the precise cut-o for defining LV hypertrophy is di cult because the value is a ected by many parameters, including body size and imaging technique. Furthermore, physical exercise training can increase wall thickness in a way that is generally thought to be healthy or positive. The general consensus is that a wall thickness greater than 1.2 cm is usually an indication of unhealthy LV hypertrophy.

Cardiac enlargement is a key predisposing step on the causal pathway that makes a firefighter susceptible to CVD events.

ECHO and CMR rely on di erent technologies and use di erent algorithms for the assessment of LV mass, providing di erent average values along with di erent degrees of precision. 22,23,24 The di erences between these methods can make the distinctions between disease states and normality harder to make. [25] Evidence suggests an improved prognostic value, when LV hypertrophy is based on the most accurate prediction of LV mass. Both LV mass and heart size increase in proportion to the overall body size and thus di er by gender, with higher values seen in men. [25,26,27] Therefore, body size parameters should be considered to normalize myocardial mass, minimizing the e ect of body size in the population distribution.[21] An LV mass “index” is derived by dividing LV mass with height, or by body surface area (BSA), or by comparing it to a reference group of healthy subjects. Height indexing seems to be the most sensitive in identifying obesity-related LV hypertrophy that is associated with CVD events and all-cause death.

LV hypertrophy and cardiomegaly have been widely recognized to increase the risk of lethal ventricular arrhythmias, myocardial infarction and stroke; and are proven to predict CVD and overall mortality in the general population. Unfortunately, these conditions have not been adequately researched in the fire service.[28-32] Current evidence from autopsies on firefighters who succumbed to SCD have shown LV hypertrophy to be common among US firefighters, often co-morbid with CHD and to play a major role in CVD events and SCD risk in the fire service. In fact, the majority of CVD death victims (60-76%) suered from LV hypertrophy/cardiomegaly, which was usually unrecognized before death. [33,34,35]

Cardiovascular Disease (CVD) Risk Factors

- *Non-modifiable:*
  - *Age*
  - *Sex*
  - *Family history*
- *Modifiable:*
  - *Hypertension*
  - *Overweight/Obesity*
  - *Dyslipidemia*
  - *Diabetes*
  - *Physical inactivity*
  - *Physical Fitness*
  - *Smoking*
  - *Diet*
  - *Sleep quantity/quality*
  - *Stress/Resiliency*

Figure 1. Conceptual Model of CVD in the Fire Service: Risk Factors, Progression (left to right) and Triggering of Events (right) in Susceptible Firefighters. Modified from Soteriades at al. (1).

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In light of the amazing advances in imaging techniques available to visualize the heart, it should be easy to measure heart size or weight – but, the truth is, there are multiple challenges to determining accurate size and weight, and even more challenges associated with knogitenEhat size is healthy and what size is pathological (unhealthy) in a given individual.

Evidence suggests an improved prognostic value

for its assessment. The two most frequently used non-invasive, imaging modalities for the assess-

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Chapter 2

Methods – Study Population 1 (Non-Invasive Assessment/ Imaging)

Male career firefighters, aged 18 years and older were recruited from the Indianapolis Fire Department. Eligible firefighters had no restrictions on duty and had a recorded fire department-sponsored medical exam in the last two years that included a submaximal exercise tolerance test.

From those eligible (n=1059), we selected at random a total of 400 participants, as follows: 100

Definitions of Cardiac Enlargement (Non-Invasive Assessment/Imaging)

LV mass was assessed by both ECHO and cardiac MRI (CMR) imaging. First, a transthoracic cardiac echocardiogram was done as a simple two-dimensional (2-D) study with limited m-mode recordings. The echocardiogram is a type of ultrasound test that uses sound waves that are sent through a device called a transducer. The device picks up echoes of the sound waves as they bounce o the di erent parts of the heart and then these echoes are turned into moving pictures of the heart that can be seen on a video screen. The transthoracic cardiac echo is the most common type, where the views of the heart are obtained by moving the transducer to di erent locations on the chest or abdominal wall.

An abbreviated CMR was also performed as "function only" immediately after the ECHO. A CMR is a painless imaging test that uses radio waves, magnets, and a computer to create detailed pictures of the heart. CMR can provide detailed information on the type and severity of heart disease to help decide the best way to treat heart problems such as coronary heart disease, heart valve problems, pericarditis, cardiac tumors, or damage from a heart attack. Board certified specialists performed the clinical interpretation of imaging.

LV mass was adjusted in standard fashion for body size by calculating an index. Three sets of commonly used indices were derived, by dividing LV mass in grams with either body surface area that was estimated with the Mosteller formula (in meters2) or body height to the powers of 1.7 and 2.7 (in meters1.7 and meters2.7, respectively).

Assessment of Cardiovascular Risk Factors (Non-Invasive Assessment/ Imaging)

- Height and weight were measured using standard and consistent clinical practices.
- BMI was calculated as the weight in kilograms divided by the square of height in meters.
- Blood pressure was measured using an appropriately sized cu with the subject in the seated position.
- Heart rate and blood pressure were obtained in a resting state from the physical examination.
- Medical exam data were further supplemented by a questionnaire that was administered before the imaging studies. The survey collected comprehensive information on smoking status, personal history of heart rhythm problems, family history of cardiac problems and moderate to vigorous physical activity level in minutes per week.
- High risk of obstructive sleep apnea (OSA) was assessed using a well-known, validated and commonly used instrument, the Berlin Questionnaire.

Chapter 3

Cardiac Enlargement in U.S. Firefighters:

population and thus anthropometric parameters should be considered to normalize LV mass, minimizing the effect of body size in the population distribution. Therefore, an LVmass "index" is usually derived by dividing LV mass with a body size parameter (i.e. body surface area, height) and then LV hypertrophy is defined by an LVmass "index" greater than some specified cutoff value.[1,2,3] Definitions may vary by the method used (ECHO or CMR) or by the method (unit) of reporting and the body size parameter used to create the index. In fact,

Table 1. LV hypertrophy prevalence estimates by ECHO and CMR.

Imaging Technique	Ranges of prevalence estimates (%)
ECHO	3.3-32.8
CMR	0.0–5.3

In the second group of data, LV hypertrophy and cardiomegaly estimates were based on the numerical values provided in the autopsy reports of the non-cardiac traumatic fatalities are presented in Table 2. Cardiomegaly was defined as a heart weight greater than 450 grams and LV hypertrophy was defined as a LV wall thickness greater than 1.2 cm.

Table 2. LV hypertrophy & cardiomegaly prevalence estimates among non-cardiac traumatic fatalities.

Condition	Prevalence estimates (%)
Cardiomegaly	33.8
LV hypertrophy	41.5

Conclusions & Discussion

The present findings in US firefighters demonstrate great variability of the prevalence estimates of LV hypertrophy within and between ECHO and CMR, according to the di□erent criteria utilized. Considerable variance was also observed using direct measures at autopsy, again, depending on the criteria used. Autopsy findings clearly indicated that BMI was a major determinant of heart weight. Prevalence estimates of LV hypertrophy were considerable, for example LV hypertrophy was present at 17.5% of the active career firefighters when using ECHO and indexing to height comparing to 33.8% prevalence based on the autopsies measurements. Although CMR is considered to be the gold standard among imaging techniques, the prevalence estimates of cardiac enlargement currently observed seemed unrealistically low, especially when compared to direct measures at autopsy in a similar firefighter population. Given the great variance in LV mass and LV hypertrophy estimates, surprisingly, average LV wall thickness was similar across both imaging techniques and at autopsies.

Among traumatic deaths, where any possible contribution of cardiac pathology to the death was reasonably excluded, as many as 40% demonstrated cardiomegaly while up to 42% presented LV hypertrophy. This can be explained in large part by the high prevalence of obesity that was documented among those non-cardiac traumatic controls.

In addition our findings suggested the presence of cardiac enlargement to be steadily increasing as a function of BMI. Our findings are consistent with the literature, which finds obesity to be a significant risk factor for LV hypertrophy and increased cardiac mass.[4,5] Furthermore, one could hypothesize that traumatic fatalities occur more frequently in obese firefighters as they could be more inclined to be physically trapped during a fire secondary to their body size and relative physical immobility.[6] In fact, the average BMI of the non-cardiac fatalities was higher than that of the active firefighter study base population (31.2 vs. 30.3) and that previously reported for representative, population-based firefighter samples (28.6 for career firefighters).[7]

To the best of our knowledge, our current study is the first to evaluate the status of cardiac enlargement among active career firefighters by both ECHO and CMR measurements based on di□erent criteria, as well as the first to compare these estimates to those derived from non-cardiac traumatic fatalities. We previously found the prevalence of cardiomegaly to be 22% in a smaller sample of non-cardiac, traumatic firefighter autopsies limited to those under the age of 45 years of age.[6] Our estimates for these age groups were similar, 27% and 24% for those under the age of 35 and 45 years of age respectively. Having access not only to data from active career firefighters, but also to autopsy reports from non-cardiac traumatic fatalities, we relied on quantitative data to estimate the prevalence of cardiac enlargement in the US fire service via several di□erent methods and get a more holistic picture.

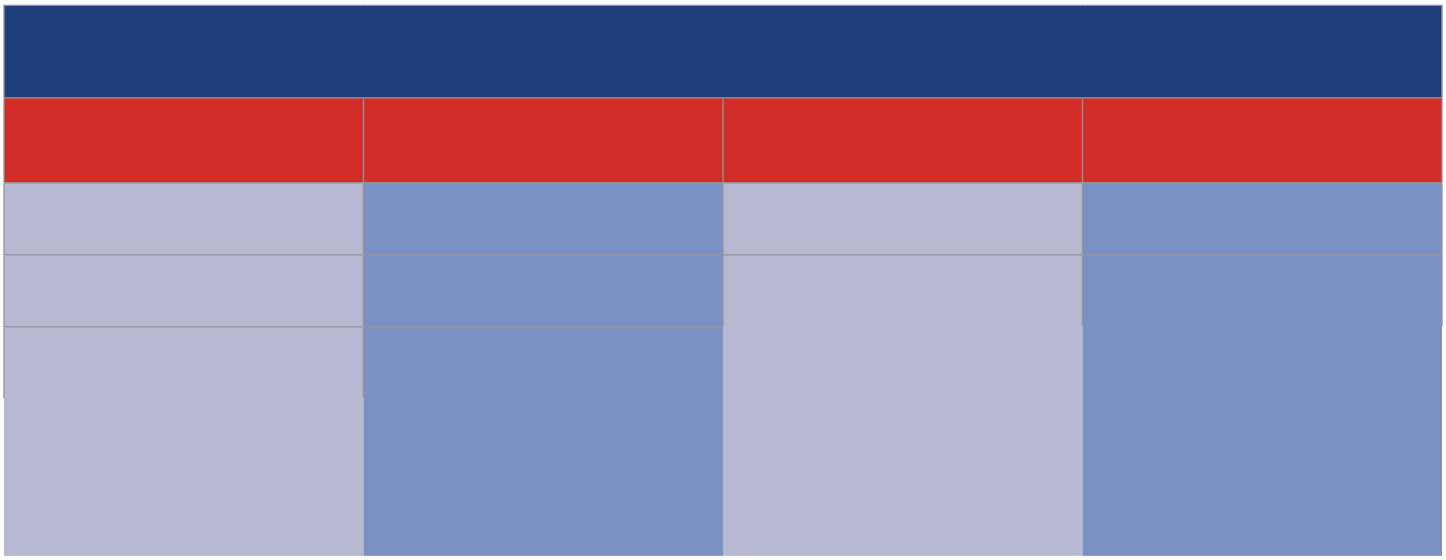
Chapter 4

E□ect of Body Mass Index on Left Ventricular Mass in Career Male Firefighters

This chapter presents the key findings from the imaging studies and, thus, identifies the most important predictors of LV mass after indexing for height among career male firefighters as assessed by both ECHO and CMR.

Findings

When assessing the ability of each CVD risk factor to separately predict the LV mass index values, resting systolic blood pressure, hypertension, high risk of OSA, low cardiorespiratory fitness and BMI were each strong (statistically significant) predictors. However, when all significant CVD risk factors were considered together at the same time, BMI was the only consistent and statistically significant predictor of LV mass index values for across all ECHO and CMR measurements and indices. Specifically, we found that a 1-unit increase in BMI was associated with 1 unit (g/m1.7) increase in the most commonly used LV mass index (g/ height in meters1.7) even after also considering age, hypertension, obstructive sleep apnea risk and cardiorespiratory fitness (table 3).



This study of active U.S. career firefighters using ECHO and CMR measurements found BMI to be the strongest and most consistent independent predictor of LV mass index values. Therefore, our findings, in line with previous studies of the general population[1,2], support BMI as a major determinant of LV mass.

Given the epidemic level of obesity in the US fire

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Chapter 5

Summary of Findings and Recommendations to Reduce Cardiac Enlargement in the Fire Service

In the second group of data, LV hypertrophy and cardiomegaly estimates were based on the numerical values The goals of this work were:

1. to evaluate cardiac enlargement (including LV hypertrophy) and assess how the di□erent non-invasive screening as well as forensic methods and reference ranges can a□ect distinctions between disease states and normality;
2. to provide more definitive prevalence estimates of cardiac enlargement among US firefighters; and
3. to identify the most significant clinical predictors of LV mass in this special occupational cohort.

Our findings provide important insights on the most appropriate method of assessing cardiac enlargement among the US firefighters. **The most important finding of our study is that BMI is an independent predictor and a major driver of LV mass, heart weight and LV wall thickness. Thus, significant reductions in on-duty CVD events could be realized by reducing obesity in the US fire service.**

Our understanding of CVD in the fire service has greatly increased over the past 15 years, with an increasing recognition in the role of cardiac enlargement. Although additional research is required to address remaining questions, this should not slow e□red5ghters;Ting a0.Tw T[not)0.5 (slow)0.5 (e

Firefighters

Firefighters are ultimately the ones who must make the changes to reduce CVD in the fire service. Making these changes will require taking personal responsibility for one's health as well as adherence to policy and procedures. Firefighters must take an active role in reducing their risk for CVD. Based on current understanding of research, firefighters should:

1. Maintain a high level of physical fitness
2. Obtain an annual physical, even if it is not provided by your department
3. Routinely monitor blood pressure and control hypertension if present
4. Maintain/take steps to reach a healthy weight
5. Avoid tobacco use
6. Eat a healthy diet – consider the Mediterranean Diet as one proven to decrease CVD and cancer risk
7. Avoid excessive use of alcohol
8. Get adequate sleep
9. In the presence of Obstructive Sleep Apnea, continuous positive airway pressure (CPAP) can produce reductions in LV hypertrophy.
10. In the presence of hypertension, anti-hypertensive drugs and particularly, angiotensin converting enzyme (ACE) inhibitors can produce echocardiographically-confirmed regression of LV hypertrophy.

Fire Department – Company O□cer/Crew Boss

Company o□cers/crew bosses have a position of great influence and should act as intermediaries to reinforce existing policies and facilitate policy touoateeuz6 Tw cers drm0.5 (ree Departicieci/Crew5nd facitL)90reaa h3ng 0daEy Tw 0 -1.5 T/Cr5

Fire Service Leadership – National Organizations

National organizations play a key role in promoting health and wellness in the fire service. These organizations influence legislation and policy decisions and set the national priorities for the fire service. Given previous findings that obesity-associated SCD among firefighters was largely driven by an increased cardiac mass in SCD victims compared to controls, our results show that decreasing obesity in the fire service will improve firefighters' cardiovascular risk profiles, including their risk of LV hypertrophy and significantly reduce on-duty CVD events, particularly SCD. Moreover, our data shows that BMI is a major driver of LV mass, heart weight and LV wall thickness. Our data also indicates that LV mass accounts for a greater proportion of total heart weight in diseased hearts compared to controls. Taken collectively our work indicates that obese firefighters are at increased risk for enlarged hearts and at greater risk for sudden cardiac events. This suggests that targeted noninvasive screening for LV hypertrophy is appropriate for obese firefighters.

Based on current understanding of research, it is recommended that fire service leaders take the following steps to prevent and manage CVD in the fire service:

1. Require pre-placement medical evaluations
2. Require annual medical evaluations
3. Require return to work evaluations
4. Implement physical fitness programs
5. Implement comprehensive wellness programs
6. Implement targeted screening for LV hypertrophy and cardiomegaly for obese firefighters, as well as those with uncontrolled or chronic hypertension or obstructive sleep apnea

Strategies to Encourage Adoption of Recommendations

The recommendations presented above are both practical and attainable, albeit not without challenges. To e□ect change, recommendations must be adopted, and there are always obstacles that must be overcome in the process.

Strategies to ensure that firefighters receive education/counseling about medical conditions following a medical evaluation. That is, what can be done to ensure that firefighters are not simply being cleared for duty (i.e., how can a medical evaluation be kept from simply being a “cleared for duty” checklist that indicates everything is ok?)

- *Individual counseling after evaluation.*
- *Personal accountability.* Designate a member of the department to whom firefighters must report to ensure that firefighters are imple-
-
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Resources to help adopt/implement recommendations

1. IAFF/IAFC WFI Resource: http://bit.ly/1KSBwy0
2. U.S. Fire Administration Health and Wellness Guide for the Volunteer Fire and Emergency Services: http://bit.ly/2rvu11l
3. NVFC Heart-Healthy Firefighter Program: http://bit.ly/2seR8dG
4. The 16 Firefighter Life Safety Initiatives: http://bit.ly/2stcnL5
5. American Heart Association web resources: http://bit.ly/IO8ENf
6. NFPA Standards: 1500, 1582, 1583, and 1584

Suggestions/ Recommendations for Future Research

We believe that future studies are needed to validate the assessment of cardiac enlargement (including LV hypertrophy), and to identify the reference values that would be most appropriate for US firefighters considering the special CVD risk profiles of this unique occupational cohort. Moreover, future forensic studies are needed to directly compare total cardiac mass to left ventricular mass, in order to establish the relationship between the two. In this regard, national fire service organizations should advocate for LV mass to be measured at firefighter autopsies (cardiac and non-cardiac) to empower us to find more precise screening definitions for high risk based on LV mass. Finally, we suggest that future prospective studies of CVD

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