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Cardiovascular Risk Factors in Career Firefighters

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Cardiovascular Risk Factors in Career Firefighters

by

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DISSERTATION

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DEDICATION

This document, and the time and effort that it represents, is dedicated to my husband, Stephen R. Nord, M.D., without whose constant love, support, and good humor this would not have been completed; to the Livermore-Pleasanton Fire Department, without whose enthusiasm, trust, and participation the research could not have been accomplished; and to Jessica and Mark, Michael, Jeffrey and Lora, Daniel and Elissa, Timothy, and Brianna who tolerated my distraction with love and understanding.

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ABSTRACT

CARDIOVASCULAR RISK FACTORS IN CAREER FIREFIGHTERS

Background: Sudden cardiac death is the leading cause of on-duty death among career firefighters. Limited literature as to the etiology of on-duty sudden cardiac death in firefighters is available. Cardiovascular risk profiles of firefighters are similar to those of the general population. Firefighters seem not to be protected from the national obesity epidemic; and hypertension and/or hypercholesteremia are often not diagnosed, or are under treated.

Methods: Accurately assessing cardiopulmonary capacity in career firefighters is critical to duty assignment and prevention of sudden cardiac death. Eighty-three male career firefighters performed maximal exercise treadmills (per the revised 2008 Wellness-Fitness Initiative (WFI)) and direct VO_2max assessments to determine the accuracy of WFI estimates of VO_2max and maximal heart rate.VO_2 and heart rate at ventilatory threshold and at maximal exercise were measured. They then wore Holter monitors and were asked to record their activities for 24 hours on duty. Subsequently, 63 career firefighters completed a sub-maximal exercise treadmill for comparison to the direct measure VO_2max and historical estimates.

Results: The WFI maximal exercise treadmill test overestimated ~ 1.16 METs; the initial WFI sub-maximal estimation over-estimated ~ 2.23 METs; and the revised WFI sub-maximal estimation was found to accurately estimate VO_2max when compared to directly measured VO_2max. Maximum heart rates on duty were analyzed to determine if measured maximal heart rate, or heart rate at ventilatory threshold, were reached. About 18% exceeded their measured maximal heart rate, 51% exceeded their measured heart

most common activity at peak 24-hour heart rate was exercising (32.5%), followed by performance drills (28.9%), pack tests (14.5%), fire suppression and overhaul (10.8%), responding to other calls (9.6%), and other (3.7%). About 90% of the participants experienced elevated heart rates while being monitored. The range of maximum METs demonstrated on duty was 4.8 to 17.0.

Implications: Excessive heart rates and work demands may contribute to cardiac compromise if there is underlying cardiovascular disease. Occupational health practitioners should advocate for accurate cardiopulmonary testing and treatment of underlying cardiovascular risk factors in career firefighters.

Approved:

OiSaeng Hong, RN, PhD
Dissertation Chairperson

CHAPTER ONE – CARDIOVASCULAR RISK FACTORS IN CAREER FIREFIGHTERS

INTRODUCTION

Line of Duty Death and Injuries

While firefighting has long commanded the public's awe and respect, the events of September 11, 2001 heightened this emotion for the general population. The significant loss of life in the line of duty re-established the inherent risks of this career choice for much of the public (International Association of Fire Fighters [IAFF], 2006). Being physically fit enough to meet significant danger as a daily event is thought to be a core requirement for firefighting (Guidotti, 1992).

In the United States from 1994 to 2004 there were 1,141 line-of-duty deaths (LODD) (excluding the World Trade Center) among the approximate 316,950 career and 823,960 volunteer firefighters (Centers for Disease Control and Prevention [CDC], 2006). The primary cause of on-duty death in both groups was sudden cardiac death (CDC, 2006).

Of the 368 career firefighter LODD that occurred between 1994 and 2004 39% were caused by heart attacks, 29% by other causes (e.g., burns, cerebral vascular accident, drowning), 20% by asphyxiation, and 12% by motor vehicle related trauma (CDC, 2006). Cardiovascular and cerebral vascular accidents can be reduced, or prevented, by early detection and treatment of underlying pathology. When these causes of death are combined they constitute the largest category of LODD and become a focus for intervention.

It is significant to note that the definition of "on-duty heart attack" was changed in December 2003. Prior to that point a heart attack was considered "on-duty" only if the firefighter began experiencing symptoms at the fire scene and died within 24 hours; after December 2003 the definition was expanded to include a death that occurred within 24 hours of a call, regardless of symptom onset (CDC, 2006). Had this definition been consistent during the 10 year review period it is likely that the number of fatalities, for both career and volunteer firefighters, would be higher. Also of considerable note is the fact that the average age of firefighters who experience sudden cardiac death is significantly younger than those who die of sudden cardiac death in the general population (44 years versus 60 years) (American Heart Association, 2008; CDC, 2006).

Career firefighters differ from volunteers in terms of extended and improved training, and better equipment. In spite of these factors the ratio of on-duty death for career firefighters is approximately 170% higher than that of volunteer firefighters (estimated rate of .0012 for career firefighters (368/316950) versus .0007 for volunteer firefighters (610/823950)) (CDC, 2006). The career fire service is predominantly male (98%) (Women in the Fire Service Inc., 2006).

A difference in LODD statistics exists between career firefighters in the United States and Canada compared to those in Europe and Australia. European and Australian career fire organizations demand annual physical fitness and medical testing to determine continued ability to serve (Ide, 1998). LODD in Europe is rare as reflected in two reports: (1) a British Broadcasting Corporation (BBC) bulletin from October 31, 2002 detailing the first on-duty death of a British firefighter in three years; the second is from a speech given to US firefighters in 2007 by Stefan Svennson, PhD, a firefighter and Research and

Development Engineer from Sweden, describing zero LODD in Sweden in the last seven years (British Broadcasting Corporation, 2002; Snowden, 2007). The strength of the IAFF in North America has prevented such testing after a firefighter has met the initial hiring requirements.

As concern about LODD rose during the 1990's, and recognizing the firefighter as "the most critical piece of equipment in the fire service", the IAFF joined with the International Association of Fire Chiefs and crafted the Wellness Fitness Initiative (WFI) (IAFF, 1999). The WFI focuses on cardiovascular fitness, medical surveillance for the respiratory and toxic exposure risks inherent in firefighting, and overall fitness for duty. While the WFI does not have the "power to retire", as happens in Europe and Australia, the intent is to achieve and maintain a higher degree of health and fitness for everyone in the fire service. The WFI has been adopted by approximately 15 of the largest departments in the United States over the last 10 years. The primary barriers to implementation are adequate cost/benefit information, limited resources, and union resistance (IAFF, 1999). In 2008 the IAFF issued the third edition of the WFI (IAFF, 2008).

There is very little in the literature about what, if any, specific or extraordinary cardiovascular risk factors career firefighters have, or the impact the WFI has had on fire departments who have initiated the program. Those departments that have participated have yet to publish findings as of the value, or lack of value, of such programs. One of the hypothesized contributors to sudden cardiac death is overexertion, but there have been no recent studies done on-duty with active firefighters to attempt to quantify the actual work demands of firefighters.

The Study Goals

The goal of this dissertation is to review the literature in an effort to better define what is known, or unknown, about cardiovascular risk factors in career firefighters, to measure on-duty work demands during regularly scheduled work shifts, and to identify changes in heart rate as it is associated with on-duty activities.

The Study's Purpose and Aims

The purposes of this dissertation research are to 1) better define cardiovascular risk factors in career fire fighters as compared to the general population; and 2) to measure on-duty heart rates to determine the work energy demands of firefighting.

Overall the results from this dissertation will be brought together to provide a clearer picture of the risks and demands of firefighting for researchers, providers, and fire service personnel that may contribute to on-duty sudden cardiac death. To meet the purpose of the study there are two specific research aims:

In male, suburban, career firefighters who have participated in the WFI:

Aim #1 - To determine if the prediction equation utilized by the WFI for aerobic capacity, as measured by VO_2max, provides an accurate assessment of cardiopulmonary work demands in firefighters.

Aim #2 -To compare (a) actual heart rate at ventilatory threshold (VT) and VO_2max to 24 hour on-duty peak heart rate, (b) document activities associated with 24 hour on-duty peak heart rate and, (c) determine the average METs expended during a 24-hour shift.

Significance

The findings from this study have the potential to further inform best strategies for prevention of LODD. This information can also help shape local and national policy through development and further refinement of occupational health standards for firefighters.

In subsequent chapters the following sequence of presentation for this dissertation is: Chapter Two includes the background for cardiovascular risk factors and their pathophysiology; Chapter Three contains the paper "Review of Cardiovascular Risk Factors in Career Firefighters" which provides a detailed review and critique of literature pertaining to cardiovascular risk in firefighters; Chapter Four contains the paper describing the "Accuracy of VO_2max Assessments in Career Firefighters" which examines four methods of assessing cardiopulmonary capacity in career firefighters ; Chapter Five contains the paper "FLAME I – Firefighters Linked to Ambulatory Monitored Electrocardiograms" which presents a study of firefighter responses to on-duty challenges compared to clinical exercise test results; Chapter Six contains an executive summary with conclusions and recommendations. References for Chapters One, Two, and Six are found at the end of the dissertation; references for Chapters Three, Four and Five are found at the end of each chapter.

CHAPTER TWO - BACKGROUND

Chapter Two provides the background and context of the pathophysiology of cardiovascular risk to facilitate an understanding for subsequent chapters. This background is important to elucidating the primary question of how to reduce, or eliminate, career firefighter LODD? At a minimum one would hope to construct a profile that allows for estimation of risk and intervention where appropriate. The approach to this dissertation was guided by McKinlay's prevention paradigm of "Upstream, Mid-Stream, Downstream" which proposes targets for prevention policy and interventions (McKinlay, 1975).

There are three approaches to disease amelioration: primary prevention, or the removal or reduction of risk factors; secondary prevention, or the early detection of disease or states that contribute to disease manifestation; and tertiary prevention (or cardiac rehabilitation), which is the aggressive risk reduction employed after an event has occurred with the intent to minimize disability and support optimum function and well being (McPhee & Pignone, 2005). It has long been hypothesized that early identification and treatment of risk factors and disease management (as compared to treating established disease) results in better outcomes and reduced mortality (Gordis, 2004). Prediction (based on research findings) is a statistical tool that is used to identify individuals, or groups of individuals, who are likely to develop a disease or a condition as a result of having one or more risk factors. Risk reduction is the concept by which interventions change risk factors that can be eliminated, or diminishes their impact, thereby reducing the overall risk of developing a disease or condition (or its severity).

Health promotion is the concept that given the right tools and knowledge, individuals or communities can make choices that will result in better health. The WFI is an example of a program whose intention is to utilize prediction, risk reduction, and health promotion to reduce the incidence of LODD for career firefighters.

Cardiovascular Disease and Pathophysiology

In 2004 an estimated 21.9% of deaths worldwide were a due to cardiovascular/ cerebrovascular events. This represents the single largest cause of death globally (Wilson, 2005; World Health Organization [WHO], 2004). The WHO and United States public health agendas include the detection, prevention, and treatment of cardiovascular disease (CVD) as important priorities due to the inherently high percentage of related health care costs, and the ability to prevent, or reduce, the burden of disease significantly with life style modification and/or treatment (Poulter, 2000, WHO, 2008).

The pathophysiology of CVD is atherosclerosis of the coronary arteries. Atherosclerosis can also manifest in the cerebral arteries (contributing to stroke) and in the peripheral circulation (often presenting as claudication and peripheral arterial disease) (Libby, 2005a).

Of concern in the firefighting population and its younger mean age of sudden cardiac death, is the fact that atherosclerotic lesions often begin developing in childhood and progress throughout the lifespan (McMahan, et al., 2005; Strong, et al., 1999). However, clinical manifestations of atherosclerosis become evident only when a high degree of atherosclerotic lesions have accumulated, such as greater than 70% occlusion in one or more lesions. It is for this reason that screening for risk factors is so important.

While there are many other forms of CVD (i.e. congestive heart failure, idiopathic cardiomyopathy, etc.) the focus of this background is atherosclerotic heart disease and its contribution to sudden cardiac death. The problem for the firefighting population is sudden cardiac death in relatively young adults. The screening process employed during the hiring process of career firefighters generally precludes other types of CVD that might be contributory to sudden cardiac death in this population (National Institute for Occupational Safety and Health, 2007).

Framingham Heart Study

In 1948 the National Heart Institute (now the National Heart, Lung and Blood Institute) and Boston University began what was to become a landmark study of heart health, the Framingham Study, in the United States. Risk factors were identified in 1976, 1991, and updated again in 1998 (Anderson, Wilson, Odell, & Kannel, 1991; Gordon, Sorlie, & Kannel, 1971; Wilson, et al., 1998). The primary risk factors originally identified included: cholesterol (total, high density lipoproteins (HDL) and low density lipoproteins (LDL)), hypertension, tobacco use, diabetes, left ventricular hypertrophy, male gender and age (Anderson, et al., 1991; Wilson, et al., 1998). Over time additional risk factors have been identified and include: obesity, physical inactivity, family history of premature CVD, ethnic characteristics, psychosocial factors, triglyceride levels, small LDL particles, homocysteine, lipoprotein(a), prothombotic factors (e.g. fibrinogen) and inflammatory markers (e.g. C-reactive protein) (Pearson, 2002; Scheuner, 2003). These latter factors are considered by some to mediate the primary risk factors (Grundy, et al., 1999).

Research has quantified the risk of those markers, as well as the effectiveness of various treatments to reduce the risk. Smoking, hypertension, hyperglycemia, male gender, high-fat diet, lack of exercise, and in women postmenopausal status, are known to negatively alter lipid profiles and to encourage the development of atherosclerotic plaques (Libby, 2005a). Consequently management, or elimination, of those contributory risk factors can prevent, or retard, the development of atherosclerotic CVD, and reduce its severity, thereby improving quality and quantity of life. These risk factors are generally categorized as “non-modifiable” and “modifiable”.

Table 1. *Cardiovascular Disease Risk Factors*

Non-modifiable	**Modifiable**
Age	Obesity
Gender	Physical inactivity
Family History	Atherogenic diet
Ethnicity	Smoking
	Hypertension
	Diabetes
	Hypercholesteremia

(National Institute of Health National Heart Blood Lung Institute, 2005)

Established Risk Factor Identification, Classification and Guidelines for Treatment

The non-modifiable risk factors are, in essence, the ones we are born with and cannot be changed. It has been established through numerous studies that being: over 65, male, or a postmenopausal female; having a family history of hypercholesteremia or premature cardiac disease (a male first-degree relative younger than 55 or a female first-degree relative younger than 65); and/or being of African-American descent contribute significantly to the risk of developing atherosclerotic CVD, with age being generally the most heavily weighted factor (Libby, 2005b).

On the other hand, by definition, the modifiable risk factors can be affected. Hence, significant research has been done on these modifiable factors, their influence on the development of atherosclerotic plaques, and the optimal interventions to prevent cardiovascular damage or disease progression. Current evidence-based guidelines are intended to reduce the likelihood of developing atherosclerotic disease by decreasing the stress on the cardiac system (weight and blood pressure management), improving the efficiency of the cardiovascular system (physical exercise), and reducing excess lipoproteins (management of hypercholesteremia). The intent of the WFI is to discover and appropriately treat those firefighters who have developed cardiac risk factors.

The first three modifiable risk factors, obesity, physical inactivity and atherogenic diet are interrelated, and have been established as precursors to CVD (Libby, 2005b). These three modifiable risk factors contribute directly to the development of other modifiable risk factors, namely hypertension, hypercholesteremia, and/or diabetes mellitus.

Obesity. In most cases, obesity is the result of increased caloric intake with insufficient physical activity to expend those calories consumed, but not required, for sustaining life and daily metabolism. Obesity contributes to the development of type 2 diabetes, hypertension and CVD (as well as other chronic conditions not currently under discussion). It is established that there is a national epidemic of obesity in the United States with an estimated 61% of the population having a Body Mass Index (BMI) ≥ 25.0 (McPhee & Pignone, 2005). In a cross-sectional study of 135 healthy males obesity was determined to be a stronger predictor of CVD risk profile than lack of aerobic fitness. This result may be limited by the small sample of subjects (Christou, Gentile, DeSouza, Seals, & Gates, 2005). Recent research on the prediction of LODD in career firefighters indicated that 90% of LODD victims, where BMI had been measured, had BMIs in the overweight or obese ranges (Geibe, et al., 2008). Obesity is a condition that can be modified by appropriate diet and increased physical activity or exercise.

Physical Inactivity. Exacerbating the observed collective increase in BMI on a national scale is a concurrent decrease in daily physical activity or exercise. Physical activity, of sufficient frequency and intensity, is known to convey multiple benefits – improved cardiovascular performance in terms of reduced blood pressure and increased aerobic capacity; metabolic benefits in terms of decreased weight or continued weight control, increased high density lipids, decreased triglyceride and glucose levels; and psychological benefits of improved self-image and decreased stress (Simon, 2000; Williams, 2001). A consistent observation that there is an inverse relationship between physical activity and the incidence of CVD is found in the literature (Powell, Thompson, Casperson, & Kendrick, 1987). As with the obesity risk factor, firefighters, on occasion, appear to be less physically active, or fit, than their community neighbors (Garver, et al., 2005; Roberts, O'Dea, Boyce, & Mannix, 2002). The standard test for the evaluation of exercise tolerance is some form of exercise testing.

Atherogenic diet. Firefighter shifts vary by department. As a general rule, many departments have a 24 hour rotating shift, although the range is from 12 hours on, 12 hours off, to 48 hours on and 96 hours off. Regardless of shift pattern, career firefighter crews are strongly bonded. Career firefighters live within two distinct cultures – the fire service with its life at the fire station, and the group (family, significant others, friends) with whom they reside when they are off duty. As on duty fire service often involves at least 24 hour shifts each life encompasses the "full life" experiences of sleeping, eating, performing tasks, and relaxing. Therefore the relationship dynamics within the firehouse will have an influence on the dietary patterns of career firefighters. An interventional study found better results with group based (crew) behavior change programs, as opposed to individual counseling, when focusing on eating choices, exercise and maintenance of body weight (Elliot, et al., 2004; Elliot, et al., 2007). The findings of obesity in firefighters may be reflective of dietary choices that are atherogenic (i.e. foods that are high in saturated fats and sugars), but there are no specific reports in the literature about the dietary habits of career firefighters.

Smoking. Smoking is known to contribute to the development of hypertension and atherosclerosis. Both smoking and hypertension are independent risk factors for atherosclerotic CVD (Burns, 2003). There have been recent legislative actions in Florida and Massachusetts which prohibit firefighters from consuming tobacco products at least while on duty, if not during the term of employment (Kales, Soteriades, Christophi, & Christiani, 2007; Ma, Fleming, Lee, Trapido, & Gerace, 2006). There has been a major decline in smoking in the United States over the last twenty years (CDC, 2005). To date there is no published data on the incidence of smoking among career firefighters. However, it has been shown that in firefighters who smoke the multivariate odds ratio for smokers experiencing a fatal coronary event is 3.68 (95% CI 1.61, 8.45) (Geibe et al., 2008).

Hypertension. Hypertension, regardless of cause, contributes to atherosclerotic CVD by encouraging thickening and hardening of arterial walls in order to withstand the stress of elevated pressures. Early hypertension is often asymptomatic and it is estimated that approximately 30% of hypertensives are undiagnosed, while many of those who are diagnosed not being treated adequately (McPhee & Pignone, 2005). The Seventh Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure (JNC7) established categories for the classification of hypertension (Table 3) (National Institute of Health National Heart Lung and Blood Institute, 2006). Uncontrolled hypertension in career firefighters (present in 49% of non-fatal and 78% of fatal cardiovascular events) was the most significant predictor for fatal coronary event, with a multivariate odds ratio of 4.15 (95% CI 1.83, 9.44) (Geibe et al., 2008).

Table 2. *Blood Pressure Categories for Adults (in mmHg) per JNC7.*

Category	Systolic	Diastolic
Normal	<120	<80
Pre-hypertension	120-139	80-89
Hypertension		
Stage 1	140-159	90-99
Stage 2	≥160	≥100

(National Institute of Health National Heart Lung and Blood Institute, 2006)
Notes:
1) If readings fall into two different categories (i.e. 120/90) the higher category (i.e. 90) is used to classify blood pressure.
2) If a person has diabetes and chronic kidney disease the cut point for hypertension is 130/80.

Diabetes. Diabetes is a chronic disease that, in and of itself, is considered a coronary heart disease equivalent, regardless of other risk factors. In other words, having a diagnosis of either Type I or Type II diabetes is the same as a diagnosis of CVD (National Cholesterol Education Program National Heart Lung Blood Institute National Institute of Health, 2001). The National Fire Protection Association's (NFPA)

Comprehensive Occupational Medical Programs for Fire Departments (NFPA 1582, 2007) states that any candidate who has insulin dependent Type 1 diabetes (Category A) cannot be hired as a career fighter. Those candidates who have Type 2 diabetes, managed with diet, exercise and oral hypoglycemics (Category B) are conditionally rejected if they have a history of one or more hypoglycemic episodes. Development of diabetes with episodes of hypoglycemia after the firefighter has been hired would require retirement if the department adheres to the NFPA Standard 1582 (2007). While there are reports of some firefighters with impaired glucose intolerance the number of diabetic career firefighters appears to be extremely low (Kales, et al., 1999). Hiring and retention policies based on NFPA 1582 are likely to reduce the incidence of diabetes in this population, thereby reducing the likelihood that this risk factor will be an important contributor to the development of atherosclerotic CVD in career firefighters.

Hypercholesteremia and triglycerides. Hypercholesteremia is defined as an abnormal amount of cholesterol in cells and plasma and is contributory to the development of atherosclerosis. Cholesterol and triglycerides are the main lipids found in blood.

Cholesterol is a sterol that is found in plant and animal tissues (such as red meat, fish, poultry, eggs and dairy products) and is a component of blood plasma and cell membranes. Cholesterol is an important precursor to the steroid hormones (i.e. estrogen, testosterone, and cortisol), vitamin D_2, and bile acids. In humans cholesterol is manufactured by the liver and absorbed from the intestine. Higher than normal amounts of cholesterol in the blood are associated with increased risk for developing atherosclerotic cardiovascular disease (Farlex, 2008).

Triglycerides are an ester of three fatty acids joined to a glycerol molecule. They occur naturally in animal and vegetable tissues and are an important energy source forming much of the fat stored by the body (Farlex, 2008).

Blood lipoproteins, particles containing cholesterol and triglyceride, are further classified by their density. Blood lipoprotein density is determined by the amount of triglyceride (which is less dense than cholesterol) and/or the amount or type of apoproteins that are present in the particle. The most dense, and smallest of the apoprotein/cholesterol molecules are known as high density lipids (HDL), the type of cholesterol most commonly referred to as "good" cholesterol. Increased levels of HDL are associated with decreased plaque formation. Low density lipoproteins (LDL) have more triglyceride and less apoprotein than HDL and are often referred to as "bad" cholesterol. Very low density lipoprotein (VLDL) is manufactured in the liver from the body's own stores of fat and carbohydrates and is composed primarily of triglyceride. LDL is created when very low density lipoproteins (VLDL) have transferred enough of the triglyceride they carry to cells to acquire sufficient increased density to be classified as LDL. Most of the cholesterol is carried on the LDL molecules in fasting serum (McPhee & Pignone, 2005).

Multiple randomized control trials have established that the lowering of the blood lipid concentrations, either by diet modification or with pharmacologic agents, can effectively reduce morbidity and mortality from atherosclerotic CVD (The Antihypertensive and Lipid-Lowering Treatment to Prevent Heart Attack Trial (ALLHAT) Officers and Coordinators for the ALLHAT Collaborative Research Group, 2002; Downs, et al., 1998; Sever, et al., 2003; West of Scotland Coronary Prevention

Study Group, 1998). These and subsequent studies led to the publication in 2001, and the 2004 validation, of the Adult Treatment Panel III of the National Cholesterol Education Program. The Treatment Panel guidelines for cholesterol are outlined in Table 4 (Grundy, et al., 2004).

Table 3. *ATPIII Guidelines for LDL Cholesterol Goals for Therapeutic Lifestyle Changes (TLC) Or Drug Therapy based on CVD Risk*

Risk Category	LDL Goal	Level at which to implement TLC	Level to consider drug therapy
CVD or CVD risk equivalents = 10 year risk > 20%	<100 mg/dL	≥ 100 mg/dL	≥130 mg/dL (100-129 mg/dL drugs are optional)
2+ risk factors = 10 year risk ≤ 20%	<130 mg/dL	≥130 mg/dL	10 year risk 10-20% ≥130 mg/dL 10 year risk < 10% ≥160 mg/dL
0-1 risk factors	<160 mg/dL	>160 mg/dL	>190 mg/dL (160-189 mg/dL drugs are optional)

(National Cholesterol Education Program National Heart Lung Blood Institute National Institute of Health, 2001)

Cardiopulmonary Capacity

The unique physical demands of firefighting, and concern about the accuracy of currently utilized exercise protocols, suggests that direct measurement of aerobic capacity during exercise testing would yield a more accurate representation of career firefighter cardiopulmonary limits. Advances in technology, improved accessibility, and reduced cost of testing equipment, make the acquisition and interpretation of this direct measurement realistic in clinical practice.

Exercise stress testing. Considerable research has been done using exercise stress testing, together with cardiovascular risk profile assessment, and as a predictive tool. In populations both with and without known CVD, exercise capacity has been shown to be a strong predictor of cardiac and all cause mortality (Dewey, et al., 2008; Kokkinos, et al., 2008; Mora, Redberg, Sharrett, & Blumenthal, 2005). Studies in asymptomatic populations support and validate these findings (Aktas, Ozduran, Pothier, Lang, & Lauer, 2004; Gibbons, Mitchell, Wei, Blair, & Cooper, 2000; Hesse, Morise, Pothier, Blackstone, & Lauer, 2005)

Exercise stress testing, with a uniquely designed treadmill protocol (known as the Gerkin Protocol prior to 2008, the WFI Protocol after 2008) (IAFF, 2008) is a critical component of the WFI for career firefighters. To date there have been no published results of the validity of this protocol, in either detecting or predicting CVD, in a population that has met WFI standards. Exercise stress testing has been used to evaluate Hazardous Material teams' participation in the fire and airline communities (Green, 2005; Raymond, Barringer, & Konen, 2005).

VO_2max. VO_2max, also known as peak VO_2, is an objective, clinical measure that defines the upper limits of cardiopulmonary performance. It directly reflects an individual's ability to increase their oxygen uptake, heart rate and stroke volume, and thus cardiac output, during the increasing physical demands of an exercise challenge, thereby directing oxygenated blood to muscles in order to work on demand. Exercising at a level beyond which the cardiopulmonary system can adequately supply oxygen (commonly termed anaerobic, or ventilatory threshold (VT)) is dramatically less efficient than aerobic muscle metabolism, and can compromise cardiovascular function (Froelicher & Myers, 2006). When VO_2max is determined in conjunction with an exercise treadmill the heart rate at VO_2max can be measured, and is recognized as the true maximum heart rate for the individual. Approximated, "maximum" heart rate is calculated as 220 – age and is often used to establish the upper, or maximal, limit for

heart activity in exercise. It may be that the “true” maximal heart rate (measured by VO_2max) is not the same as the “predicted” maximal heart rate (220 – age). The variability of this estimation is high and therefore may not serve the clinician, or perhaps career firefighters, well.

Changes in VO_2max closely parallel maximal cardiac output and are being used increasingly in multivariate studies as a significant determinant of cardiac survival (Froelicher & Myers, 2006). As VO_2max declines with age it is very difficult to project “normal” values – in essence, “normal” for an individual is what they can actually achieve when VO_2max is measured. Even so, the relationship between age and VO_2max is very imprecise as demonstrated by very low correlation coefficients ($r = 0.35$, $p < .001$) which makes any prediction based on age questionable (Myers, 1997).

Prediction

The premise underlying cardiovascular risk reduction theory is the ability to identify those individuals who are at risk and to intervene in such a manner as to avoid, or mitigate, an adverse outcome. The Framingham Risk Equation (FRE) and similar algorithms are the primary means used in health care to make those identifications. Risk reduction is based on the theories of probability. Probability is a statistical method used to determine the relative frequency of an occurrence, or the proportion of times an event occurs, in a large number of trials repeated under similar conditions (Pagano & Gauvreau, 2000). Probability is based, in part, on Bayes Theorem, which says that if the probability of a mutually exclusive occurrence is known (i.e. CVD or a coronary event), and new information comes to light, the new information can be added which may, or may not, alter the original probability (or prediction) that an event will (or will not) occur

(Pagano & Gauvreau, 2000). The algorithms, based on regression equations, predict absolute and relative risk for an individual who is currently free of CVD.

Risk estimation, either absolute or relative, is at best an imprecise science. Analysis of the algorithms demonstrates that while tools may be highly reliable it is exquisitely more difficult to establish their validity – sometimes even in the context for which they were designed. Numerous potential new risk factors have been identified but not been studied extensively to see if they improve validity. Including the variable of exercise stress testing in asymptomatic individuals has demonstrated improved risk prediction using the FRE (D'Amore & Mora, 2006; Mora, et al., 2005). Quantification of coronary artery calcium in asymptomatic individuals has also been shown to refine the FRE in several studies (Arad, Goodman, Roth, Newstein, & Guerci, 2005; Nasir, Vasamreddy, Blumenthal, & Rumberger, 2006; Taylor, et al., 2001). C-reactive protein has not demonstrated an ability to improve the FRE to date (Arad, et al., 2005; Wilson, 2005; Wilson, et al., 2005).

The demographics of American career firefighters closely resemble the Framingham population. Of primary concern is the fact that many firefighters are under age 35 and the FRE has been shown to not address younger populations with much accuracy. However, validation studies do indicate that the FRE would be an appropriate tool to use for predicting risk in this group if one adjusted the age risk factor to 60 (from the actual age) when other risk factors are identified (Poulter, 2000). Until there is a more accurate prediction tool the FRE could be used in this population with the age adjustment.

Conclusion

As a result of mandated entrance requirements most career firefighters begin their careers without many of the primary and secondary risk factors known to contribute to CVD such as age, hypertension, tobacco use, diabetes, obesity, or physical inactivity, and yet career firefighter risk of experiencing a CVD related LODD is evident. It is unknown if this is related to CVD risk factors acquired during their career (either by lifestyle choice or exposure), to the physical demands imposed by firefighting tasks, the normal aging process, or a combination of the three. Establishing which tools effectively identify at risk career firefighters and promote the appropriate interventions (and thereby improve cardiovascular risk profiles), is imperative to reduce the incidence of sudden cardiac death among on-duty career firefighters.

Determining if there is excessive all-cause or CVD mortality in career firefighters will be necessary for framing and defining the problem of LODD in career firefighters. Examination of career firefighters' unique CVD risk profiles will contribute to that definition. A clear understanding of the research to date on the cardiopulmonary energy demands imposed by firefighting tasks will illuminate the gaps in the literature.

CHAPTER THREE – REVIEW OF CARDIOVASCULAR RISK FACTORS IN CAREER FIREFIGHTERS

Abstract: Sudden cardiac death is the leading cause of on-duty death among firefighters. Determining firefighter risk of cardiovascular death or all-cause mortality, cardiovascular risk factor profiles, and energy demands while firefighting may help to understand why this occupational group is at risk for on-duty sudden cardiac death. A literature review conducted between 2006 and 2009 did not demonstrate that firefighters are at increased risk of all-cause death compared to the general population. In addition, cardiovascular risk profiles of firefighter are similar to those of the general population. Firefighters may be part of the national obesity epidemic; their hypertension and/or hypercholesteremia are often not diagnosed or are under treated. The combination of personal cardiovascular risk factors and extreme physical work demands may contribute to sudden cardiac demise in this population.

Keywords: firefighter, male, sudden cardiac death, mortality, cardiovascular, obesity, hypertension, lipids, aging, fitness, occupational health.

INTRODUCTION

North American firefighters are mostly males who are relatively young (53.7% ages 20-39, 41.3% ages 40-59, 5% over age 60) (United States Fire Administration, 2007). Many retire between 50 and 55 due to the extreme physical demands of firefighting, but are also encouraged by incentives for early retirement. There are significant expectations by the public of these servants, the most basic of which are that firefighters will be safe for themselves, their colleagues, and the community.

Between 1994 and 2004 there were 368 on-duty deaths (excluding the World Trade Center) among 316,950 career firefighters in the United States (Centers for Disease Control and Prevention [CDC], 2006). The "cost" of these deaths includes the emotional toll on families and colleagues, employee deficit, loss of knowledge, and direct financial impact on the community and families. Of these deaths 39% were heart attacks, 29% other causes (e.g., burns, cerebral vascular accident, drowning), 20% asphyxiation, and 12% motor vehicle related trauma (CDC, 2006). Considering the significant number of deaths related to cardiovascular disease (CVD) among firefighters, it is important to identify their risk factors and develop intervention programs to prevent or reduce fatality through early detection and treatment. Therefore the purpose of this study is to identify risk factors of CVD in firefighters through an extensive literature review. Specifically this review targets three questions: 1) What are the energy demands imposed by firefighting? 2) What is the CVD risk profile in firefighters? And, 3) Are firefighters at greater risk of all-cause or cardiovascular mortality?

METHODS

An extensive literature review was conducted using several library databases such as PubMed and the Cumulative Index of Nursing and Allied Health Literature (CINAHL) between 2006 and 2009. Keywords included: firefighter, male, sudden cardiac death, mortality, cardiovascular, obesity, hypertension, lipids, aging, fitness and occupational health. This review was limited to peer-reviewed studies published in English and excluded female career firefighters.

A total of 198 articles were identified by CINAHL and PubMed in peer-reviewed journals. CINAHL citations appearing in non-peer reviewed journals (n = 2989) were not included for review. 123 citations in PubMed met the stated inclusion criteria of: male, career, sudden cardiac death, fitness for duty, mortality, cardiovascular, obesity, hypertension, lipids, aging, fitness, and on-duty monitoring. Letters, redundant chapters and technique reviews were excluded leaving 59 articles for inclusion in this paper.

Healthy Worker Effect (HWE). A consideration when discussing firefighter mortality is the impact of the "Healthy Worker Effect" (HWE). The HWE is "an observed decrease in mortality in workers when compared to the general population" (Choi, 1992). Standardized Mortality Ratio (SMR) is an indirect age adjustment statistic used to compare death rates due to a certain cause between an occupational group and the general population (Gordis, 2004). An SMR of 100 is equal risk between groups; less than 100 indicates fewer deaths than expected; over 100 indicates more deaths than expected (Gordis, 2004). The HWE generally accounts for a 20-30% reduction in mortality in SMRs (Choi, 1992).

Findings

Findings of the literature review are organized to answer three questions.

1. What are the energy demands imposed by firefighting?

Efforts to define work energy demands of firefighting have focused on determining the metabolic equivalent (METs) levels required to safely carry out fire suppression duties. A MET is a multiple of the resting metabolic rate and is commonly estimated using standardized equations (Froelicher & Myers, 2006). The range of METs suggested or observed in the literature is from 9.6 (Sothmann, Saupe, Jasenof & Blaney, 1992) to 14 (Malley et al., 1999). This is at best an imprecise measure, but gives an approximate estimation of relative effort needed for a given task. A measure of 10 METs is roughly equivalent to jogging a 10-minute mile; 14 METs is similar to many extended competitive activities such as running or rowing competitively, or bicycle racing at a high level (Fletcher, Froelicher, Hartley, Haskell, & Pollock, 1990).

Comparison of heart rates, with varying weights of self-contained breathing apparatus during simulated fire drills, found that heart rate increased to 70-80% of maximum predicted within the first minute of the exercise, regardless of type or weight of breathing gear. Heart rate continued to increase to 90-100% of predicted maximum and remained there until the fire was extinguished (Manning & Griggs, 1983)

Maximum heart rate and VO_2max in firefighters who perform maximal work on a stair-climbing machine versus a treadmill showed the stair-climbing machine resulted in significantly lower VO_2max and maximum heart rate without wearing personal protective equipment (PPE) (Ben-Ezra & Verstraete, 1988). Similarly, 10 firefighters completed sub-maximal treadmill tests with VO_2max measurements; they then completed a set of simulated tasks in PPE (Sothmann et al., 1991). While heart rate with suppression tasks was not significantly different than heart rate at exhaustion on the treadmill, VO_2max with simulated suppression tasks was significantly less than predicted by the treadmill (Sothmann et al., 1991).

Researchers and firefighters collectively determined the most strenuous tasks in firefighting (reported in order of difficulty) as (1) carrying equipment up stairs in a high-rise building; (2) advancing charged hoses; (3) breaking down doors, walls, ceilings, and roofs; (4) raising ladders; (5) working overhead, and (6) rescuing victims (Gledhill & Jamnik, 1992). The most difficult tasks (i.e. numbers 1 and 2) required 11.9 METs, representing 85% of VO_2max (Gledhill & Jamnik, 1992). The less arduous tasks (i.e. numbers 5 and 6) required 6.6 METs, which represented 50% of VO_2max (Gledhill & Jamnik, 1992).

Another study compared task simulations in three different uniforms to a baseline maximum stress treadmill and actual VO_2max measured in gym clothes (Malley et al., 1999). Each firefighter repeated a treadmill test to exhaustion on three separate occasions, wearing three separate uniforms (traditional, modern, and modified modern), including PPE. Traditional uniforms had polyester/cotton long pants, long-sleeved shirt, a long overcoat and high boots; the modern uniform had the same pants, short-sleeved shirt, shorter overcoat and shorter boots; the modified modern uniform had a cotton T-shirt, polyester/cotton shorts, and the same overcoat and boots as the modern uniform. Regardless of uniform type each firefighter surpassed their anaerobic threshold at one minute, 70% of their VO_2max by three minutes, and 90% of their VO_2max by the end of the exercise, and reached their maximum heart rate (Malley et al., 1999). This study showed a negative relationship between age and VO_2max, and that uniform type influenced exercise time significantly.

In contrast to objective measurements, self-perception of fitness and measured aerobic capacity did not demonstrate a relationship (Peate, Lundergan, & Johnson, 2002). A total of 92 firefighters completed a self-assessment of their fitness level and had VO_2max estimated from two different tests (5-minute step test and a sub-maximal stress treadmill). There was no association between the firefighters' self-perception of fitness and estimated aerobic capacity (Peate et al., 2002).

Twelve firefighters randomly exercised on graded treadmill tests to exhaustion in gym clothes, and then in full PPE. VO_2max in the PPE condition was 17.3% lower than in the gym clothes condition (Dreger, Jones, & Petersen, 2006). All of these studies reinforce that the energy demands of firefighting are significant and studies of the accuracy of the firefighter self-perception of effort remain inconclusive.

2. What does the cardiovascular risk profile of firefighters look like?

Overall Firefighter Cardiovascular Risk Profiles. The RISKO cardiac index, (Michigan Heart Association, 1967) was calculated for 4,066 Los Angeles County safety personnel, of whom 1825 were firefighters. Compared to lifeguards, marshals and sheriffs, firefighters had the second lowest risk score despite being the oldest cohort (Thomas, Cady, O'Connell, Bischoff, & Kershnar, 1979).

In 1982 firefighters were matched to Veterans enrolled in the Normative Aging Study in Boston and were followed-up for ten years (Dibbs, Thomas, Weiss, & Sparrow, 1982). The findings concluded that firefighters were at lower risk for developing cardiovascular disease than the comparative population of Veterans (Dibbs et al., 1982).

Of the 43 on-duty deaths in North Carolina between 1972 and 1985, 23 were due to cardiovascular disease (Fort & Griggs, 1987). Only six of the 23 victims had a history of cardiovascular disease, highlighting the need for earlier identification and intervention.

In a study by Licciardone and colleagues (1989) 452 firefighters in Dallas, Texas, ages 18 to 59, had complete physical examinations, serum chemistry and lipid profiles, resting and exercise stress electrocardiograms (ECGs), and body fat assessment. Hypercholesteremia and obesity were commonly found, but Framingham Risk Equations (National Institute of Health National Heart Blood Lung Institute, 2005) of the cohort did not differ from those of age-matched men in the general population (Licciardone et al., 1989).

Between 1984 and 1992, 806 Cincinnati firefighters participated in comprehensive periodic examinations, including a thallium treadmill (Glueck et al., 1996). This study reported that firefighting was not associated with an increase in cardiovascular event rates. Cardiovascular disease that did develop was related to modifiable risk factors (i.e. blood pressure, cholesterol, cigarette smoking), and that there was no relationship between the incidences of smoke inhalation during fire suppression and cardiovascular deaths.

The most-studied firefighter cohort to date is in Massachusetts where the relationship between cardiovascular risk factors and fitness for duty was explored in Hazardous Material (HazMat) firefighters (Kales, Aldrich et al., 1999). The study stated that lower predicted aerobic capacity (VO_2max) and lower spirometric function, combined with an increase in age, cholesterol, and weight, resulted in increased cardiovascular risk. More importantly, their findings underscore the concept that not just one indicator, but often multiple factors, predisposes firefighters to cardiovascular disease.

A 2003 case control study using national data compared 52 male cardiovascular on-duty deaths to 51 male non-cardiovascular on-duty deaths between 1996 and 2002, and to the male subjects of the HazMat cohort from Massachusetts (n = 310) (Kales, Soteriades, Christoudias, & Christiani, 2003). An important finding was the time of cardiovascular death – firefighters most often experience cardiac demise between noon and midnight, whereas the general population most frequently succumbs to cardiovascular events between 6 am and 12 pm, regardless of work shift pattern. The time of firefighter death pattern corresponds to the period of high intensity emergency dispatches in most fire departments. The second significant finding was the increased odds of firefighter cardiac death being associated with fire suppression activities (Kales et al., 2003). Traditional risk factors (age, smoking, diabetes, and hypertension) were found more frequently among the victims of cardiovascular death than the controls.

Firefighter Framingham risk equation scores (based on a one-time physical examination and laboratory evaluation) were compared to Framingham risk equation scores of an age-matched "healthy" group (same age, optimal blood pressure, total cholesterol between 160-199 mg/dl, high density lipoprotein (HDL) ≥ 45 mg/dl, no diabetes or tobacco history). The percent of firefighters exceeding the "low coronary heart disease risk category" for each factor ranged from 40-87% (Byczek, Walton, Conrad, Reichelt, & Samo, 2004). The firefighters as a group had a higher prevalence of obesity, lower HDL, higher low density lipoprotein (LDL), and higher total cholesterol than the comparison group of a "healthy" population (Byczek et al., 2004).

Comparing 362 Massachusetts firefighters who qualified for “heart presumption retirements” (deemed a compensable Workers’ Compensation injury or illness) between 1997 and 2004 with the Massachusetts HazMat cohort (of 1997 and 2004); researchers concluded that of the retirement group, 42% of the retirements were related to on-duty events (Holder, Stallings, Peeples, Burress, & Kales, 2006). Retiree cardiovascular risk factors (age, current cigarette smoking, diabetes, and/or prior arterial occlusive disease) were all independent significant predictors of heart disease presumptive retirement, with age being the strongest predictor. This analysis also determined that the risk of an on-duty event was highest with fire suppression activity (OR = 51; 95% CI: 12, 223) (Holder et al., 2006).

When the relationship of firefighter activity to risk of cardiac event is examined it was determined that while only 1-5% of firefighters’ time on task is spent on actual fire suppression the majority of cardiac events take place during suppression activities. Cardiovascular LODD was associated with fire suppression (32.1%); responding to an alarm (13.4%); returning from an alarm (17.4%); engaging in physical training (12.5%); attending non-fire emergencies (9.4%); and performing non-emergency duties (15.4%) (Kales, Soteriades, Christophi, & Christiani, 2007).

The seasonality of firefighter cardiovascular on-duty death does not appear to match the seasonality of cardiovascular death in the general United States population for spring and summer but does in the winter (Mbanu et al., 2007). When type of duty preceding death was included in the analysis over time of year of death, the risk of fire suppression related on-duty death is highest in winter (32%), lowest in the spring (15%), spikes to 30% in the summer, and is 23% in the fall.

There were 87 acute on-duty cardiovascular deaths among all firefighters between 1996 and 2006 (National Institute for Occupational Safety and Health, 2007). The cardiovascular risk profile of this group was compared to 113 firefighters who experienced a non-fatal, on-duty, career ending cardiovascular events in Massachusetts between 1997 and 2004 in an effort to determine if there were any specific predictors of a fatal cardiovascular event. Current smoking, hypertension, or previous diagnoses of cardiovascular disease, carotid stenosis, or peripheral arterial disease were significant predictors of a fatal outcome in on-duty events (Geibe et al., 2008).

Specific Cardiovascular Risk Factors. Obesity. A generally utilized formula for determining obesity is the "Body Mass Index" (BMI), which is calculated by taking body weight in kilograms and dividing it by height in meters squared (McPhee & Pignone, 2005). The majority (87%) of the Massachusetts HazMat cohort had a BMI over 25, with 34% over 30 (Kales, Polyhronopoulos, Aldrich, Leitao, & Christiani, 1999). The mean BMI was 28.9, which is above the 85th percentile for men from the National Health and Nutritional Examination Survey II data (NHANES II, 1984). Accepting the limitation of BMI to distinguish between fat and muscle mass (Jette & Sidney, 1990) this percentage indicates that a higher proportion of firefighters are obese than the general population (Kales, Polyhronopoulos et al., 1999).

Analysis of Texas firefighters yielded similar results (Clark, Rene, Theurer, & Marshall, 2002). Using BMI criteria proposed by the World Health Organization (2008) 80% of the sample were classified as being overweight to obese (BMI ≥ 25). Using the "standard" criteria by Kales, et al., (1999), 60% were classified as obese. Allowing a BMI of 25-26.9 to represent increased muscle mass, the majority of these subjects (mean

BMI = 28.8), remain above the 85th percentile of the general population (Kales, Polyhronopoulos et al., 1999).

At baseline the average BMI of the HazMat cohort was 28.9 (± 4.1) (Kales, Polyhronopoulos et al., 1999); after five years it increased by 0.8 to 29.7 (± 4.3) (Soteriades et al., 2005). The prevalence of obesity (BMI > 30) increased significantly during the study period from 34.9% in 1996-1997 to 39.7% in 2001; more importantly, extreme obesity (BMI > 40) increased four-fold during the same period (Soteriades et al., 2005). Cardiovascular risk factors (age, smoking, hypertension, increased total or LDL, decreased HDL, and increased fasting glucose) were also associated with weight increase.

Analysis of obesity and job disability in the HazMat cohort demonstrated that for every unit increase in BMI there was an associated 5% increase in risk of job disability (Soteriades, Hauser, Kawachi, Christiani, & Kales, 2008). Obesity has previously been linked to cardiovascular events at work; it also possibly puts firefighters in danger of acquiring non-cardiac career ending disabilities.

The national obesity epidemic is being reflected in firefighter and emergency medical response recruits. Of 370 firefighter (n = 210) and ambulance (n =160) recruits (aged 18 to 34) examined in Massachusetts between 2004 and 2007, 43.8% were overweight (BMI 25-29.9) and 33% were obese (BMI > 30) (Tsismenakis, et al., 2009). Of equal concern is the association between increased BMI and increased blood pressure ($p < .04$), higher total cholesterol ($p < .003$) and decreased exercise tolerance ($p < .001$) (Tsismenakis, et al., 2009).

Hypertension. The first of three hypertension studies of the HazMat cohort showed that 10% of the study population had blood pressures higher than 140/90 (Stage I hypertension per the 6th Joint National Committee on the Prevention, Detection, Evaluation and Treatment of Hypertension guidelines (JNC6)) (Kales et al., 1998; National Institute of Health National Heart Lung and Blood Institute, 1997). The second study showed that firefighters with Stage II hypertension (JNC6, >160/100 mm/Hg), and who were not receiving treatment, were two to three times more likely to experience adverse employment events or outcomes (retirement, termination, any injury or illness) when compared to the normotensive, or treated hypertension groups (Kales et al., 2002). Both groups were adjusted for age, BMI, smoking, cholesterol and medication. Stage II hypertensives were also found to be older and more obese than their Stage I and normotensive colleagues (Kales et al., 2002).

The third study directly addressed untreated Stage I hypertension (>140/90) (Soteriades, Kales, Liarokapis, & Christiani, 2003). At baseline (1996) the prevalence of Stage I or higher hypertension in this cohort was 20%; in 1998 and 2000 it was 23%. At each examination period only 17% (1996), 25% (1998), and 23% (2000) of those diagnosed were taking antihypertensive medication. Approximately 74% of the cohort with identified hypertension was left untreated, or inadequately controlled, after four years of follow-up (Soteriades et al., 2003). Of additional concern is the fact that these findings were based on the JNC6 guidelines; were this analysis to be done using the lower JNC7 guidelines the percentage of hypertensive, and pre-hypertensive firefighters would increase (National Institute of Health National Heart Lung and Blood Institute, 2006).

There is a recent recommendation that emergency responders (including firefighters) be subject to duty limitations for untreated/uncontrolled hypertension similar to those found in Department of Transportation licensing. Based on the level of hypertension firefighter assignment would range from full to modified duty with a prescribed time period to bring the hypertension under control (Kales, Tsismenakis, Zhang & Soteriades, 2009).

Lipids. The average cholesterol level of the HazMat cohort declined from 224 mg/dl at baseline to 214 mg/dl at follow up, and the percentage of hypercholesteremic career firefighters who were being treated increased from 3% at baseline to 12% at follow up (Soteriades et al., 2002). However, the percentage of hypercholesteremic career fire fighters at baseline and follow-up who were untreated remained large (78%) (Soteriades et al., 2002).

The Promoting Healthy Lifestyles: Alternative Models' Effects (PHLAME) study assigned 33 firefighters into one of three groups: team intervention, one-to-one intervention, and usual care. The goal was to determine the effectiveness of interventions on daily physical activity, diet, and body fat. At baseline the average LDL in all three groups was above the optimal treatment guideline levels; at follow-up both the team and the one-to-one intervention group demonstrated a statistically significant ($p < .05$) reduction in LDL as compared to the usual care group (Elliot et al., 2004).

Age. Age, particularly for men above 65 years, is the most significant risk factor for cardiovascular disease (Libby, 2005). Cardiopulmonary fitness, as measured by heart rate, VO_2max (aerobic capacity), and stroke volume, decrease with advancing age (Britton et al., 2007; Hollenberg, Ngo, Turner, & Tager, 1998). The "early retirement" of firefighters would seem to reduce their potential acquisition of cardiovascular disease while actively employed as a firefighter. However, this may not be of benefit as the average age at cardiac related on-duty death is 44 years (CDC, 2006).

Age may well be a bona-fide occupational criterion for firefighting, particularly as it relates to cardiopulmonary fitness, most notably, VO_2max (Sothmann, Landy, & Saupe, 1992). The first described range of VO_2max deemed necessary to perform fire suppression activities was 25-35 ml/kg^{-1} x min^{-1} (Sothmann, et al., 1991). Review of subsequent literature recommended that firefighters, regardless of age, have a VO_2max of 33.6-42 ml/kg^{-1} x min^{-1}, which would allow for reserve above the observed work demand (Sothmann, Saupe, Jasenof & Blaney, 1992; Malley et al., 1999).

The effect of aging on firefighters was observed over 17 years in a California suburban department (Davis, Jankovitz, & Rein, 2002). Comparing physical fitness results of younger (20-29 years) and older firefighters (50-59 years): VO_2max decreased 27.7%; push-ups decreased 45.6%; sit-ups decreased 40%; flexibility decreased 9.6%; and body fat increased from 13.3% to 22.4% (Davis et al., 2002). However, when compared to the general population firefighters were more fit than the general public in all age groups (Davis et al., 2002). While firefighters appeared to maintain a better than average levels of fitness, the overall decline with time, especially in aerobic capacity, is of concern.

Cardiovascular risk factor findings showed that firefighters were closely aligned with their age-matched NHANES comparison group. However, over the 17 years of observation the percentage of firefighters who acquired cardiovascular risk factors is considerable. Comparing younger (20-29 years old) to older firefighters (50-59 years old) the presence of: hypercholesteremia increased from 21.7% to 73.7%; LDL (greater than 130) increased from 18.8% to 78.9%; total cholesterol to HDL ratios over 5 increased from 16.7% to 31.6%; and hypertension increased from 12% to 31.6% (Davis et al., 2002).

3. Are firefighters at greater risk of all-cause or cardiovascular mortality?

All cause mortality. Thirteen studies representing study periods ranging from 18 to 61 years, spanning the years 1915 to 2000, and were published between 1959 and 2005. The all-cause SMR ranged from 52 (Ma, Fleming, Lee, Trapido, Gerace, Lai et al., 2005) to 152 (Sardinas, Miller, & Hansen, 1986). Mortality outcomes were obtained from searches of vital statistics records, death certificates, cancer registries, motor vehicle department records, pension records and fire department records.

A Connecticut study compared firefighters with police officers and the general population of men and reported an SMR of 152 (Sardinas et al., 1986). Reasons for this elevated SMR are not presented, nor has this study been replicated. Over the same time period, New Jersey firefighters (whose deaths were between 1974 and 1980) were compared to Caucasian men in the general population in New Jersey, and found a SMR=100 (Feuer & Rosenman, 1986). This finding does not demonstrate any HWE.

A Florida cohort of 34,796 firefighters demonstrated an SMR=57 for male firefighters (Ma et al., 2005). This may be relative to a younger, more recent (1972-1999) cohort with 27 years of follow-up. This study, if early rates persist over time, is a strong example of the HWE.

A study from Seattle had SMR=76 (Heyer, Weiss, Demers, & Rosenstock, 1990), which increased to 81 when Tacoma and Portland firefighters were added to the analysis

(Demers, Heyer, & Rosenstock, 1992). The HWE impact was less evident in a number of other studies: San Francisco, SMR=90 (Beaumont et al., 1991), Boston, SMR=91 (Musk, Peters, Bernstein, Rubin, & Monroe, 1982), Buffalo (Vena & Fiedler, 1987), and Toronto SMRs = 95 (Aronson, Tomlinson, & Smith, 1994), Edmonton/Calgary (Guidotti, 1993) and Philadelphia SMRs = 96 (Baris et al., 2001).

Of interest is the lack of HWE found in these studies. Several studies demonstrated SMRs that approached or exceeded 100 despite possible lifestyle changes and the introduction of sophisticated PPE in the late 1970's. Of additional interest is the question why SMRs that do demonstrate HWE are not larger as firefighters, at selection, were free of chronic diseases, most notably diabetes (Choi, 2000). With a few exceptions however, firefighters have all-cause mortality rates that are generally lower, even if only by a few percentage points, than the general population.

Cardiovascular mortality. Comparing firefighters to the general Ontario male population there were 157 observed cardiovascular deaths versus 111 expected (Mastromatteo, 1959). It should be noted that this cohort of firefighters was on active duty from 1918 to 1954, a time period when there was limited access to self-contained breathing apparatus, resulting in significantly higher exposure to carbon monoxide and other toxins. There is no SMR reported. This citation regarding firefighters and cardiovascular deaths may have established the concept of "presumption" for heart disease in many states' and provinces' for Workers' Compensation laws and torts (International Association of Fire Fighters [IAFF], 2008). Toronto firefighters cardiovascular death rates compared to the City of Toronto cardiovascular death rates between 1975 and 1979 demonstrated an overall adjusted cardiovascular death SMR=173

(Bates, 1987). Again, the majority of this cohort's career span preceded the use of self-contained breathing apparatus.

There was no association between cardiovascular mortality and occupation found in Boston (Musk et al., 1982), Connecticut (Sardinas et al., 1986), New Jersey (Feuer & Rosenman, 1986), Buffalo (Vena & Fiedler, 1987), San Francisco (Beaumont et al., 1991), Seattle, Tacoma, Portland (Demers et al., 1992), Edmonton/Calgary (Guidotti, 1993), Toronto (Aronson et al., 1994), and Florida (Ma et al., 2005). When Seattle was studied independently those firefighters with more than 30 years employment had a cardiovascular SMR of 103 (Heyer et al., 1990); and in Philadelphia the cardiovascular SMR = 109 was statistically significant (Baris et al., 2001).

The literature indicates that firefighters, regardless of where they work, do not appear to be at increased risk for cardiovascular death, with some exceptions for career spans that preceded the use of sophisticated PPE. Of concern are the variable time periods of the cohorts, and the latency associated with cardiovascular disease. As the studies encompassed the years between 1915 and 2000 changing awareness of lifestyle risks, such as the relationship between tobacco use and cardiovascular disease; and expanded use of PPE, may have contributed to a reduction in cardiovascular deaths in the later study periods. The overall data does not suggest that firefighters are at increased risk for cardiovascular disease, and most studies demonstrate cardiovascular SMRs below 100.

Discussion

This review is limited by studies that have small sample sizes with significant self-selection bias. Much of the published work has been limited to groups that do not represent the geographic or age diversity of most firefighters. Early research is focused on whether or not firefighting as an occupation increases cardiovascular risk, more contemporary work is focused on the energy demands of firefighting.

The impact of demanding hard work with heavy gear is repeatedly established in the literature. When one considers the demands of their work being done in a stressful environment, with extreme temperatures, space and time constraints, smoke, noise, dust and chemical exposures, it is reasonable to assume that cardiac stress might be significant. Based on the previously discussed findings of Peate et al. (2002), inaccurate self-perception of fitness could lead to inappropriate judgment of ability to complete a task under duress.

The cardiovascular risk profile consists of non-modifiable risk factors (age > 65; male; positive family history of cardiovascular disease in a first degree relative; and ethnicity), and modifiable risk factors (obesity; physical inactivity; diet; smoking; hypertension; diabetes; hyperlipidemia; and possibly stress and alcohol use) (National Institute of Health National Heart Blood Lung Institute, 2005). Male firefighters have at least one non-modifiable risk factor (gender), and may have family history and ethnicity factors as well (being over age 65 is unlikely). Based on this review of three modifiable risk factors (obesity, hypertension and hyperlipidemia) it appears that firefighters have risk profiles similar to the general population. They may be overweight; and have hypertension and hypercholesteremia that is often undetected and or under treated. There may have been a greater occupational risk to firefighters prior to the wide spread use of PPE, but currently there is no evidence that firefighters have an increased risk of all cause mortality, or cardiovascular mortality, when compared to the general population. In general, firefighters have slightly lower levels of cardiovascular mortality than the general population but not as much as would be expected in a population that is initially selected for its fitness and lack of evident pre-existing disease. The loss of the HWE over time may be, in part, due to the stress and extreme work demands of firefighting. The primary problem, however, appears to be that firefighters may succumb to the same epidemic of obesity, untreated hypertension, and/or hyperlipidemia as seen in the general population, and that those morbidities may be negatively impacting the HWE as well.

Conclusion

It would appear that firefighters in North America do not show protection from the HWE. This may in part be due to the obesity epidemic, untreated hypertension and/or hyperlipidemia, and increased risks associated with age. Firefighters also have extreme energy demands from their work. All of these factors may contribute to the incidence of cardiac related on-duty death.

There are multiple opportunities for occupational health nurses and nurse practitioners to intervene with this population to reduce modifiable risk. Areas of prime influence are nutrition and cardiovascular status (including education and access to healthy foods, healthy weight goals) (IAFF, 1999), and continued focus on heart healthy behaviors (appropriate use of PPE, smoking cessation, exercise).

Occupational health nurses and nurse practitioners are uniquely positioned to counsel firefighters directly, as well as design programs within fire departments to assess risk, develop and implement various intervention programs, evaluate the effects of interventions, and perhaps most importantly, convey the unique demands and risks of firefighting to community health providers. Given the findings of major risk factors in firefighters, an argument can be made that early detection of risk, as well as ongoing surveillance of firefighters who are identified to have cardiovascular risks factors, is justified and deserves evaluation. This review illustrates the effectiveness of medical surveillance, as well as the frustration of being unable to rectify the problem without the support and assistance of primary care providers. It is unknown if the "disconnect" between diagnosis and treatment is related to firefighter communication, or primary care providers not understanding the unique requirements of firefighting and its potential toll on the cardiovascular system. Occupational health nurses and nurse practitioners can intervene to help firefighters and primary care providers better understand the risks associated with untreated cardiovascular risk factors in firefighters, and the need for aggressive evidence based risk reduction interventions (Soteriades et al., 2003).

The aim of prevention is to monitor cardiovascular risk status, encourage healthy behaviors, and implement timely and appropriate interventions to reduce morbidity and mortality in firefighters. These efforts will be beneficial to firefighters, their families, the fire service, and the communities they serve.

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CHAPTER FOUR – ACCURACY OF VO_2MAX ASSESSMENTS IN CAREER FIREFIGHTERS

Abstract

Introduction: Sudden cardiac death is the leading cause of on-duty death among firefighters in the United States. Assessing cardiopulmonary capacity is critical in determining duty assignment and preventing sudden cardiovascular events.

Methods: 83 male firefighters performed maximal exercise treadmill tests (2008 Wellness-Fitness Initiative (WFI)) and direct VO_2max assessments. 63 career firefighters completed sub-maximal exercise treadmill tests for comparison to directly measured VO_2max and historical estimations. Four VO_2max assessment methods were compared: directly measured VO_2max, WFI maximal exercise treadmill estimation, and pre- and post-2008 WFI sub-maximal treadmill estimation.

Results: The WFI maximal exercise treadmill overestimated ~ 1.16 METs, the initial WFI sub-maximal estimation overestimated ~ 2.23 METs, and the revised WFI sub-maximal estimation was found to accurately estimate VO_2max when compared to directly measured VO_2max.

Conclusions: Estimation of cardiopulmonary fitness is improved with the revised 2008 WFI sub-maximal equation.

Keywords: firefighter, Wellness-Fitness Initiative, cardiovascular risk, VO_2max, ventilatory threshold, sub-maximal exercise treadmill, maximal exercise treadmill.

INTRODUCTION

Every 19 seconds a fire in the United States requires the services of a career or volunteer fire department (United States Fire Administration [USFA], 2007). Firefighting is a dangerous job that entails running into burning buildings or wild land spaces, working for extended periods in extreme temperatures while wearing cumbersome clothing and heavy equipment, exposures to multiple toxins, and a willingness to risk one's life for the protection of fellow citizens. Sudden cardiac death is the most common cause of on-duty death among firefighters and occurs at higher rates than those found in similar occupations (USFA, 2006).

Cardiovascular events can be reduced, or prevented, by early detection and treatment of underlying pathology. In an effort to address preventable causes of death, and to improve the overall health and well-being of career firefighters, a joint task force of the International Association of Firefighters (IAFF) and International Association of Fire Chiefs was formed. The Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI) was first introduced in 1997, and revised in 1999 and 2008 (IAFF, 2008). The WFI recognizes the fire fighter as the "most important asset" in the fire service. The program is intended to improve function, effectiveness, and quality of life, while reducing morbidity and mortality related to fire fighting.

A major component of the WFI is assessment of firefighter cardiopulmonary capacity, either with a stepmill test, sub-maximal exercise treadmill, or a maximal exercise treadmill. The WFI mandates that firefighters have a maximal exercise treadmill test at age 40 and every other year thereafter.

VO_2max, also known as peak VO_2, is an objective, clinical measure that defines the limits of cardiopulmonary function. VO_2max directly reflects an individual's ability to increase their heart rate and stroke volume, and redirect oxygenated blood to muscles for work on demand. Exercising at a level beyond which the cardiopulmonary system can adequately supply oxygen (commonly termed the anaerobic or ventilatory threshold, or VT) involves anaerobic muscle metabolism which is dramatically less efficient than aerobic metabolism, and can compromise cardiovascular function (Froelicher & Myers, 2006).

Quantifying the energy demands of firefighting, as measured by VO_2 (and its corresponding heart rate) at VT, or at VO_2max, during fire suppression is difficult due to the inherent dangers of the tasks. Most efforts to accurately define physical work demand requirements during career firefighting have been focused on establishing the level of metabolic equivalents (METs) (1 MET ≈ 3.5 mL of O_2/kg/min) required to safely perform the arduous work of fire suppression using simulated tasks. A MET is a multiple of the resting metabolic rate and is commonly estimated using standardized equations (Froelicher & Myers, 2006). The estimated METs proposed for firefighting ranges from 9.6 (Sothmann, Saupe, Jasneof & Blaney, 1992) to 14 (Malley, et al., 1999). This equates to a VO_2max range of 33.6 $ml/kg^{-1} \cdot min^{-1}$ to 49 $ml/kg^{-1} \cdot min^{-1}$. In daily life 10 METs is roughly equivalent to jogging a 10-minute mile; 14 METs is similar to many extended competitive activities, such as running or rowing competitively, and bicycle racing at a high level (Fletcher, Froelicher, Hartley, Haskell, & Pollock, 1990). Recent analysis of a candidate physical aptitude test demonstrated that male firefighter recruits' average VO_2 requirement was 38.5 $ml/kg^{-1} \cdot min^{-1}$, or 73% of VO_2max, to complete a timed simulated firefighting assessment course (Williams-Bell,Villar, Sharratt, & Hughson, 2009). Measurement of functional capacity in 23 firefighters suggested that a mean of 41.54 $ml/kg^{-1}\cdot min^{-1}$ is required to complete standard fire suppression tasks while wearing personal protective equipment (Adams, et al., 2009).

As firefighting work demands can be extreme, accurate assessment of cardiopulmonary status, as well as detection and treatment of any underlying cardiovascular disease, is critical to insure firefighter fitness for duty and prevent on-duty cardiac events or death. It is therefore crucial that assessments of cardiovascular status be accurate. The sub-maximal exercise test in the 1999 WFI has been found to overestimate true VO_2max in individual firefighters (Mier & Gibson, 2004). Overestimations could result in inaccurate exercise prescriptions, inappropriate duty assignments, and above all, place firefighters with inadequate cardiac reserves in compromising situations. The concern about overestimation led to a revised estimating equation for sub-maximal exercise treadmills in the 2008 edition of the WFI.

Given that previous sub-maximal exercise test results in the WFI were shown to overestimate VO_2max, and that the maximal WFI (Gerkin) Protocol had not been validated in the literature, the validity of the revised sub-maximal exercise equation and maximal exercise results was examined. The null hypotheses were to test: (a) the current estimated WFI maximal exercise VO_2max will not differ from directly measured VO_2max; (b) estimated peak heart rate (220 – age) will not differ from actual peak heart rate; and (c) the 2009 WFI sub-maximal estimated VO_2max will not differ from directly measured VO_2max. Hypothesis (d) tested that there is no difference between the historical sub-maximal estimated VO_2max and the 2009 sub-maximal estimated VO_2max.

This paper is part of a larger study that evaluates the energy demands of firefighters in response to exercise testing in the clinical setting and during on-duty activities. There were no women suppression firefighters in this department which is consistent with national firefighter statistics as women only represent 1.8% of the fire service (Women in the Fire Service Inc., 2006).

METHODS

A cross-sectional study design was used to determine exercise capacity, which provides the answers to null hypotheses a, b and c. Previously completed WFI sub-maximal exercise tests performed in the same setting using the same procedures were used for comparison to the 2009 sub-maximal estimates for hypothesis d. The results of the larger study are reported in Chapter 4.

Setting and Sample

The setting was a medium-sized suburban fire department in the eastern region of the San Francisco Bay Area in northern California. All firefighters assigned to suppression duties, were recruited, including firefighters, firefighter/paramedics, firefighter/engineers, firefighter/captains and battalion chiefs. All testing took place during a five week period between December, 2008 and January, 2009. Inclusion criteria required that each participant had successfully completed a WFI exam within the previous nine months and achieved a minimum of 10 METs (VO_2max of 35 ml/kg/min), on either a sub-maximal (using the earlier equation), or maximal Gerkin (now WFI) protocol for treadmill testing. Exclusion criteria included injury, illness or scheduling conflicts that precluded testing during the study period.

The study was conducted with approval of the University of California San Francisco Committee on Human Research. Signed informed consents were obtained from each participant. The department and union local approved that all testing could be done during on-duty hours.

Testing occurred at an occupational health clinic where all previous WFI examinations for this fire department were conducted. All treadmills were performed by a physician board certified in internal medicine and occupational medicine, and a nurse practitioner experienced in exercise testing. Participants arrived on the day of scheduled testing with their regular crew, with gym clothes and running shoes appropriate for completing a maximal exercise test.

Measurements

Data collection consisted of medical record abstraction for demographics, cardiovascular risk factors and exercise test information.

Demographics. Age, rank, and years of fire service were obtained.

Cardiovascular Risk Factors. Cardiovascular risk factors were assessed using standards from the American Heart Association, Adult Treatment Panel III (ATP III), The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure (JNC7), and the Centers for Disease Control for assessment of obesity, (American Heart Association, 2008; Centers for Disease Control and Prevention, 2009; National Institute of Health National Heart Lung and Blood Institute, 2001, 2006). All serum samples were analyzed at the same hospital-based certified laboratory (Centers for Medicare and Medicaid Services Clinical Laboratory Improvements Amendments (CLIA)).

Maximal Exercise Treadmill with Direct VO2 max Assessment. Maximal exercise treadmills using the 2008 WFI Protocol and direct VO_2max assessments were done on all 83 participants. Treadmill tests were considered complete when the firefighter indicated volitional fatigue, or if terminated by the testing physician due to concerns about cardiopulmonary distress. The 2008 WFI protocol, a modified ramp protocol (formerly the Gerkin Protocol), is comprised of a 3-minute warm-up period at 3 mph – 0% grade, followed by fifteen 1 minute stages. Stage 1 begins at 4.5 mph and 0% grade, the treadmill incline increases 2%, and speed increases by 0.5 mph alternately in stages 2 through 15. VO_2max estimates from the maximal treadmill test are based on the American College of Sports Medicine metabolic equation for running and are calculated and produced as part of the output for the maximal exercise electrocardiogram (American College of Sports Medicine, 2000).

Pre-2009 Sub-maximal Exercise Treadmill Assessment. Prior to the 2008 revision of the WFI there was no published equation for the estimation of VO_2max from the sub-maximal exercise treadmill. A table in Appendix A of the 1999 WFI determines the estimated VO_2max based on duration of test and stage achieved (IAFF, 1999).

For each participant between one and seven sub-maximal tests (historical) were available. These historical sub-maximal VO_2max estimates were averaged for each participant for comparison to the 2009 sub-maximal estimate.

2009 Sub-maximal Exercise Treadmill Assessment. Of the 83 firefighters who volunteered for the maximal exercise treadmill test and directly measured VO_2max, 63 completed their annually scheduled WFI examination within the following three months, which included a sub-maximal treadmill test. These sub-maximal exercise treadmill tests were completed under identical conditions as the maximal treadmill tests but without the VO_2 measurement. The 2009 sub-maximal treadmill test uses the WFI treadmill protocol (see above) but is terminated 15 seconds after the firefighter reaches their target heart rate.

In 2008 the WFI introduced a revised estimation equation for the calculation of VO_2max: $VO_2max = 56.981 + (1.242 \text{ x } TT) – (0.805 \text{ X } BMI)$, where TT is the test time required for target heart rate to be met or exceeded, and BMI is Body Mass Index. After 2008 the target heart rate is calculated by (208 – (0.7 x age) x 0.85; previous calculations were based on (220-age) x 0.85.

Procedure

Height, weight and resting blood pressure was obtained for each participant. A resting electrocardiogram (ECG) was completed, using the Welch-Allyn Schiller AT-10 6-Channel electrocardiograph/treadmill (San Diego, California). Upon completion of the resting ECG the Mason-Likar lead configuration was modified to accommodate the exercise treadmill (Froelicher & Myers, 2006). The participant was then fitted with the appropriate 2-way non-rebreathable mask (Hans-Rudolph, Inc., Shawnee, Kansas) to eliminate extraneous room air from affecting the interpretation of VO_2max. VO_2max was obtained using the Cardio Coach CO_2^{TM} VO_2 Fitness Assessment System, Model 9001-RMR (Korr Medical Technologies, Salt Lake City, Utah). Detailed procedures are available from the corresponding author.

The Cardio Coach CO_2^{TM} is an economical, portable metabolic testing device that is feasible for use in a clinic and has been previously validated at VO_2max levels (Clinical Exercise Research Center Division of Biokinesiology and Physical Therapy at the School of Dentistry, 2009; Jensky, Vallejo, Ong, & Schroeder, 2005). The Cardio Coach CO_2 is a dual gas analyzer (O_2 and CO_2) that automatically calibrates to standard temperature and pressure, dry (STPD) at the beginning of each testing cycle. Heart rate was measured using the Polar T-31 heart monitor (Polar, Inc., Lake Success, NY). Heart rate and VO_2 (ml/min and ml/kg/min), VCO_2 (ml/min and ml/kg/min), VE/VO_2, VE/VCO_2, VE in L/min, FeO_2%, Fe CO_2%, and RER are graphically reported every 15 seconds. VT was detected using the ventilatory equivalents method (Ve/VO_2) (Korr Medical Technologies, 2009).

Statistical Analyses

A dependent t-test was used to test the difference between estimated and directly measured VO_2max, and estimated and directly measured peak heart rate. Pearson's correlation coefficients were used to test the relationship between the estimated and measured values. The difference between estimated and measured VO_2max was graphed with a Bland-Altman plot (Szaflarski & Slaughter, 1996).

One to seven sub-maximal test values were averaged for each individual to create a historical variable. A dependent *t*-test compared each participant's historical sub-maximal mean and the 2009 sub-maximal exercise treadmill value. A Pearson's correlation coefficient demonstrated the relationship between the historical average (old equation) and the new, refined equation. All dependent *t*-tests were two tailed, $\alpha = 0.05$. Statistical analyses were done with SPSS Version 15.0 (SPSS, Inc., Chicago, Illinois).

RESULTS

There were 105 active suppression male career firefighters eligible for participation in the study. Of those, five were new hires who had not completed a WFI examination. Six more firefighters chose not to participate; of the 94 choosing to participate 11 could not be scheduled for maximal exercise treadmills and VO_2 measurements due to injury, illness or scheduling conflicts resulting in an *n* = 83 for this study. Firefighters, firefighter/paramedics, firefighter/engineers, firefighter/captains and battalion chiefs were represented in this study.

The participants' ages ranged from 26 to 57, mean = 41.1 (± 6.9); 94% were Caucasian, and 6% were Hispanic or African-American. The years of firefighting ranged from 2 to 34, mean = 15.6 (±7.5 years). Cardiovascular risk factors are detailed in Table 1.

Comparison of Estimated and Measured VO_2max and Maximal Heart Rate

The results of the 83 participants estimated and measured VO_2max and estimated and measured heart rate at VO_2max are displayed in Tables 2 and 3. In Table 2, the statistically significant difference between estimated and measuredVO_2max is 4.06 (mean), with a 95% confidence interval (CI): 2.88, 5.23. Similarly, the estimated maximal heart rate and measured maximal heart rate differed statistically significantly by 4.96 (mean), 95% CI: 3.03, 6.90 (Table 3).

Comparisons between 2008 Sub-maximal Exercise Treadmill Estimation, Measured VO_2 max, and Historical Sub-maximal Estimations

Sixty-three participants completed sub-maximal exercise treadmill tests, using the revised 2008 equation, during the 2009 WFI examinations. Their average age was 40.19 (± 6.9) and years of firefighting was 14.4 (± 6.8). All active firefighter ranks were represented in this sub-group. The examination allowed a comparison of directly measured METs to the 2009 sub-maximal estimates, and the 2009 sub maximal results to averaged historical sub-maximal exercise treadmill results, the findings are detailed in Tables 4 and 5 respectively.

The directly measured 2009 METs compared to the estimated 2009 METs did not differ, indicating that the revised 2008 estimating equation is a reasonable estimate of METs (convertible to VO_2max by multiplying by 3.5) (Table 4). This represents additional validation of the new estimating equation (IAFF, 2008).

Table 5 shows that a statistically significant difference was found between 2009 sub-maximal estimates and historical sub-maximal estimates (2.23 (mean), with a 95% CI: 1.86, 2.60). The 2008 estimating equation results are similar to the directly measured method, and historical averages compared to the revised equation are higher than directly measured METs or estimated 2009 METs. These findings provide support for the overestimation of sub-maximal VO_2max by the pre-2008 WFI (Mier & Gibson, 2004).

Discussion

Fire departments often struggle to determine fitness for duty for their members who return from an injury or illness, or prepare to embark on a wild land fire strike team or heavy rescue mission, or for daily assignments. There are ongoing efforts to define minimally acceptable and safe fitness levels. These limits must be informed by the energy requirements needed during a firefighter's tour of duty. The only three studies that report heart rate changes and/or energy demands of actual fire suppression activities (not wild land) were reported in 1981, 1987 and 1992 (Kuorinka & Korhonen, 1981; Lim, Ong, & Phoon, 1987; Sothmann, Saupe, Jasenof, & Blaney, 1992). Proposed energy expenditures required for firefighting have been established during simulated drills (Sothmann, Saupe, Jasenof & Blaney, 1992; Malley, et al., 1999). While simulated drills are a useful approach, they may be less emotionally intense, and better controlled, than actual emergency situations, and may therefore need substantiation in the actual setting.

Limitations and Strengths. The limitations of our study include the self-selection bias of the participants, the narrow demographics of the group, and the range in number of historical sub-maximal exercise tests, resulting in a less than ideal comparison group. While testing was completed within a four month period, it included the winter holiday season which may have had a seasonal influence on fitness behavior. The composition of the sample is reflective of the department in terms of gender and ethnicity.

The strengths of this study include the number of participants, their range in age, rank, firefighting experience, and their experience with the WFI protocol. The availability of seven years historical data can also be viewed as a strength. Use of the mask to measure VO_2max was not unknown to the participants as they routinely work with self-contained breathing apparatus. The ability to perform all testing components while on duty encouraged participation. There were no incentives offered for participation. All testing was completed in the same facility using the same equipment and personnel, thus increasing consistency of testing, and therefore inter-rater reliability.

Discussion. The ability to accurately assess physical fitness is critical and determination of cardiopulmonary status is appropriate. We compared four different methods of assessment: the direct measurement of VO_2max, the estimated VO_2max derived from a maximal exercise treadmill test, the estimated VO_2max derived from the revised (2008) sub-maximal exercise treadmill equation, and the historical average of estimated VO_2max sub-maximal exercise treadmills (prior to 2009).

Directly measured VO_2max is the most objective and considered the "gold standard" of the four methods (Froelicher & Myers, 2006). Therefore, directly measured VO_2max results were used for comparison with the other three methods. The advantage of the maximal exercise treadmill test is that it allows for observation the heart's response to exercise stress. Inappropriate blood pressure, rhythm, or ST-T wave responses can indicate underlying disease and prompt an in-depth cardiovascular review.

Assessment of direct VO_2max and maximal exercise treadmill test results indicate that the equation utilized by the WFI maximal treadmill over-estimates VO_2max by an average of 4.06 $ml/kg^{-1}\cdot min^{-1}$, or 1.16 METs. If a firefighter's fitness level is less than optimal, or if they have underlying cardiovascular disease, this overestimation could lead to on-duty clearances that could prove compromising.

The difference observed in maximum heart rate between directly measured maximum heart rate (while wearing a non-rebreathable mask), and 220-age (which is part of the maximal exercise treadmill estimation equation) provides some explanation for the over-estimation. Estimated maximal heart rates were about 5 beats per minute higher than those measured during peak exercise. Heart rates are often used on the fire ground to evaluate if a firefighter is capable of re-entering the fire scene. Using heart rates that exceed true maximums, or percentages of estimated maximum heart rates that are inaccurate, could also result in dangerous duty assignments.

It has been reported that the previous sub-maximal treadmill equation overestimated VO_2max, and therefore, it was suggested that the previous sub-maximal treadmill equation should not be used for duty assignment decisions (Mier & Gibson, 2004). Due to these and other concerns a revised WFI sub-maximal exercise treadmill equation was published in 2008 (IAFF, 2008). This study compared directly measured VO_2max to 2009 sub-maximal results, based on the revised equation (n =63), and found that there were no differences between the two assessment methods (direct measure METs = 12.64 (± 2.59), sub-maximal estimated METs = 12.46 (± 1.28), p = .761). The sub-maximal treadmill tests were conducted four to eight weeks after the maximal exercise treadmill tests. Similarly, we found that the revised estimation equation for the WFI is satisfactory in predicting VO_2max.

To further evaluate the 2008 sub-maximal estimation equation 2009 sub-maximal results were compared to the averaged historical sub-maximal results for each participant. We observed that the historical mean exceeded the revised equation mean by 2.23 METs, and these findings confirm that the pre-2008 WFI sub-maximal treadmill equation overestimated VO_2max.

Clinical Implications. Firefighters who were tested using earlier estimation equations may require careful explanation as to a noticeable drop in test results using the 2008 equation. Participants are likely to be disappointed, or discouraged, to see a noticeable reduction in their “fitness level” when they have not changed their patterns or work-out habits between testing cycles. Again, if a firefighter falls into the lower fitness categories, or has underlying (and perhaps undetected or untreated) cardiovascular disease, this large difference could contribute to cardiac compromise.

In order to protect firefighters from threatening cardiac situations it is imperative that testing results are accurate, whether the test is being used for duty assignment, or as part of a comprehensive risk assessment. The results from the 2008 revised sub-maximal estimation equation more accurately reflect directly measured VO_2max results. Maximal treadmill results should be interpreted with caution, especially as they appear to over-estimate METs by an average of 1.16. This over-estimation and high variability is graphically illustrated with a Bland-Altman plot (Figure 1) (Szaflarski & Slaughter, 1996). In clinical application the upper and lower limits of agreement (± 2 SD = 7.34 $ml/kg^{-1}{\cdot}min^{-1}$, or 2.1 METs) are unacceptable, especially if a firefighters' actual METs are less than 10. Given the potential for over-estimation of fitness, providers who make fitness-for-duty assessments should consider the energy requirements of the job, any underlying cardiovascular risk factors, and the method of testing method used when recommending return to, or continuation of, duties.

When comparing 2009 WFI results to previous years of testing, or to reports in the literature, careful consideration must be given to which estimation method was used. The same task, measured with different estimating equations, can result in different results as demonstrated here.

Conclusion

In summary, the WFI maximal exercise treadmill estimate statistically significantly over-estimates VO_2 by an average of 4.06 $ml/kg^{-1}{\cdot}min^{-1}$ (or 1.16 METs), and heart rate by an average of 5 beats per minute. The newly revised 2008 WFI sub-maximal estimation equation offers an accurate estimate of cardiopulmonary fitness when compared to directly measured $VO_{2.}$ Comparing historical WFI sub-maximal estimates to 2009 WFI sub-maximal estimates confirms that the 2008 revised estimating equation provides for more accurate estimates. Collectively, these findings support the continuation and further expansion of reliable exercise testing of firefighters, within the context of a cardiovascular disease prevention program, such as the WFI.

Performing measured VO_2max and maximal exercise treadmill tests might be challenging for many fire departments to accomplish due to limited resources. The sub-maximal exercise treadmill test in the 2008 WFI is designed so that it can be safely administered outside of a medical setting using tools that are often available within the fire department (treadmill, stopwatch, and Polar heart monitor). The intention of the sub-maximal treadmill test is to obtain a safe, non-invasive, objective measure of cardiopulmonary status. The disadvantage of the sub-maximal treadmill test over the maximal treadmill test is the limited means for assessing underlying cardiovascular conditions, and the inability to determine maximal cardiovascular performance. A significant portion of the WFI is dedicated to on-duty fitness training allowing departments to focus on ways to improve firefighter aerobic capacity and cardiovascular fitness. The 2008 sub-maximal treadmill estimation equation is a valid tool to assess interim progress in cardiovascular training programs.

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Table 1

Participant Cardiovascular Risk Factor Profile – Maximal Exercise Treadmill-VO_2max Assessment (n = 83)

Risk Factor	Mean, SD	95% CI – Lower	95% CI – Upper
BMI	28.21 (± 3.9)	27.35	29.07
Systolic BP	116.93 (± 9.63)	114.81	119.04
Diastolic BP	68.83 (± 7.13)	67.26	70.39
Total Cholesterol*	196.53 (± 37.87)	188.26	204.80
HDL**	47.42 (± 11.31)	44.95	49.89
LDL**	126.07 (± 35.70)	118.28	133.87
Cholesterol Ratio	4.35 (± 1.17)	4.10	4.61
Triglycerides	117.71 (± 69.86)	102.46	132.97

*-fasting

**- HDL - high density lipoprotein; LDL – low density lipoprotein

Table 2

Comparison of Estimated VO_2max and Measured VO_2max (n = 83)

Variable	Mean, SD
Estimated VO_2max	47.71 (± 7.13)
Measured VO_2max	43.65 (± 9.12)

Dependent t-test: Mean difference 4.06, 95% CI: 2.88, 5.23, p <.001.

Table 3

Comparison of Estimated Maximal Heart Rate and Measured Maximal Heart Rate (n = 83)

Variable	Mean, SD
Estimated maximal HR	178.59 (± 6.91)
Measured maximal HR	173.63 (± 10.75)

Dependent t-test: Mean difference 4.96, 95% CI: 3.03, 6.90, p < .001.

Table 4
Comparison between 2009 Sub-maximal Exercise Treadmill Estimation in METs and Measured VO2 max in METs (n = 63)

Variable	Mean, SD
Measured METs	12.64 (± 2.59)
Estimated 2009 sub-maximal METs	12.58 (± 1.28)

Dependent t-test: Mean difference .06, 95% CI: -.39, .54, $p \leq .761$.

Table 5
Comparison between Historical Sub-maximal Exercise Treadmill Estimation in METS and 2009 Sub-maximal Exercise Treadmill Estimation in METs (n = 63)

Variable	Mean, SD
Historical estimated METs	14.81 (± 2.14)
Estimated 2009 sub-maximal METs	12.58 (± 1.28)

Dependent t-test: Mean difference 2.23, 95% CI: 1.86, 2.59, $p < .001$.

FIGURE CAPTIONS

Figure 1

Bland-Altman Plot - Direct VO_2max versus Mean Difference Predicted VO_2max - Direct VO_2max

The blue dashed line represents the mean (4.06), and 11.4 and -3.28 (green dashed lines) represent the upper and lower limits of agreement, respectively.

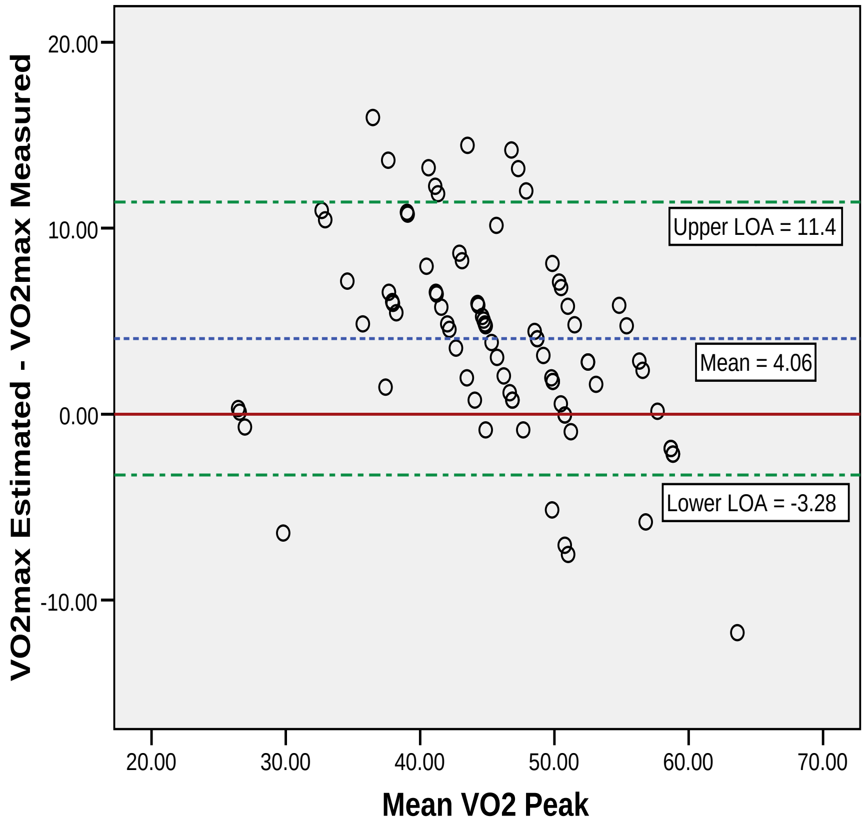
VO2max Estimated - VO2max Measured
20.00
10.00
0.00
-10.00
Upper LOA = 11.4
Mean = 4.06
Lower LOA = -3.28
20.00
30.00
40.00
50.00
60.00
70.00
Mean VO2 Peak

Figure 1.

CHAPTER FIVE – FLAME I – FIREFIGHTERS LINKED TO AMBULATORY MONITORING ELECTROCARDIOGRAMS

- A First Look

Abstract

Introduction: Little is known about the energy expenditure required during actual fire suppression and normal on-duty activities in the fire service. Excessive energy demands may be a contributing factor to sudden cardiac death, especially when underlying cardiovascular disease is present.

Methods: 83 career male firefighters wore Holter monitors for 24 hours on duty. Maximal on-duty heart rates are compared to heart rate at ventilatory threshold, and volitional fatigue, previously established with a maximal exercise treadmill and direct VO_2max measurement.

Results: 89.1% experienced elevated heart rates on-duty. 18% exceeded maximal exercise heart rate; 51% exceeded heart rate at ventilatory threshold; 20.5% were tachycardic while on duty. The order of activity at peak 24-hour heart rate was exercising (32.5%); performance drills (28.9%); pack tests (a specific fitness test) (14.5%); fire suppression/overhaul (10.8%); responding to other calls (9.6%); other (3.7%). The range of maximum METs observed during on-duty monitoring was 4.8 to 17.0.

Keywords: career, male, firefighter, on-duty monitoring, 24-hour Holter, maximal heart rate, METs, ventilatory threshold, activity.

INTRODUCTION

The Problem - Line of Duty Death

Uncontrolled fire poses a threat to lives and property. Responding to this danger requires dedicated individuals who are trained and equipped to extinguish the fire and eliminate the peril. Firefighting is an inherently dangerous job that is physically strenuous, often performed in compromised situations, and engenders multiple emotions. To be a firefighter requires an acknowledgment that the potential for the "ultimate sacrifice" is a daily event.

The career fire service is quasi-military in its organization and structure. Discipline and the sacrifice of individual rights is the accepted norm. The military ethos of "leave no one behind" is a significant part of the fire service culture. Career firefighters make a conscious choice, not unlike those who enlist in the military, of accepting the "duty to serve"; with the full knowledge of the requirements and potential sacrifice the job may demand. The initial selection process is rigorous and designed to ensure that the firefighter is physically, mentally, emotionally and morally fit to perform the required tasks (International Association of Fire Fighters [IAFF], 1999).

There are significant expectations of these public servants; the most basic of which is that in order to fulfill their obligation to save lives and property they will be safe for themselves, their colleagues, and the community they serve. It is in the sponsoring communities' best interest to value the health and fitness of its firefighters. The short term benefit to the community is a fire service that is physically able to meet the challenge of their profession – the long term benefit is a potential reduction in health care, workers' compensation, pension and death benefit costs.

In the United States in 2006 there were approximately 316,950 career firefighters and 823,950 volunteers (Karter & Molis, 2006). Between 1994 and 2004 there were 1,141 line–of-duty deaths (LODD) in the firefighting population, excluding the World Trade Center tragedy (Centers for Disease Control and Prevention [CDC], 2006). The primary cause of LODD is sudden cardiac death (CDC, 2006). When compared to similar occupations, including police and emergency medical services, firefighters have the highest percentage of heart disease related occupational deaths (United States Fire Administration, 2006). Of additional concern is that the average age of sudden cardiac death in career firefighters is 44, whereas the average age of sudden cardiac death in the general population is 60 (American Heart Association, 2008; CDC, 2006).

Concern about LODD rose during the 1990's and led to the development of the Wellness-Fitness Initiative (WFI), a joint effort of the IAFF and International Association of Fire Chiefs (IAFF, 1999). This initiative focuses on cardiovascular fitness, medical surveillance for the respiratory and toxic exposure risks inherent in firefighting, and overall fitness for duty. Recent studies have shown that the highest risk of sudden cardiac death in career firefighters occurs during fire suppression and physical training activities (Kales, Soteriades, Christophi, & Christiani, 2007). The WFI was recently revised to reflect new knowledge, technology, and information (IAFF, 2008).

Sufficient physical fitness to sustain significant physical exertion in a hazardous environment as a daily event is thought to be a core requirement for firefighting (Guidotti, 1992). Quantifying the energy demands of work (METs), as measured by heart rate at ventilatory (anaerobic) threshold (VT) and/or VO_2max, during fire suppression is difficult due to the inherently episodic and dangerous nature of the work. Most of the studies about energy demands have been obtained from simulated tasks. Establishing the level of metabolic equivalents (METs) required to safely perform the arduous work of fire suppression has proven difficult. A MET is a multiple of the resting metabolic rate and is commonly estimated using standardized equations (Froelicher & Myers, 2006). The estimated METs required to be a firefighter ranges from 9.6 (Sothmann, Saupe, Jasenof & Blaney, 1992) to 14 (Malley, et al., 1999). This equates to a VO_2max range of 33.5 $ml/kg^{-1}\cdot min^{-1}$ to 49 $ml/kg^{-1}\cdot min^{-1}$. In daily life 10 METs is roughly equivalent to jogging a 10-minute mile; 14 METs is similar to many extended competitive activities, such as running or rowing competitively, and bicycle racing at a high level (Fletcher, Froelicher, Hartley, Haskell, & Pollock, 1990). Candidate physical aptitude tests utilized for admission to the fire service demonstrated that male recruits' average VO_2 requirement was 38.5 $ml/kg^{-1}\cdot min^{-1}$ (11 METs), or 73% of VO_2max to complete a timed simulated firefighting assessment course (Williams-Bell, Villar, Sharratt, & Hughson, 2009). Measurement of functional capacity requirements in 23 firefighters suggests that a mean of 41.54 $ml/kg^{-1}\cdot min^{-1}$ (11.9 METs) is required to complete standard fire suppression tasks while wearing personal protective equipment (Adams, et al., 2009). Additionally, it has been demonstrated that medical examinations for firefighters do not adequately simulate the cardio-respiratory demands found in fire suppression activities (Angerer, Kadlez-Gebhardt, delius, Raluca, & Nowak, 2008).

Three studies cite data from on-duty cardiac monitoring. The sample sizes (*n* = 22, 49 and 10, respectively) were small and the most recent was published in 1992 (Kuorinka & Korhonen, 1981; Lim, Ong, & Phoon, 1987; Sothmann, Saupe, Jasenof, & Blaney, 1992). Two studies showed an increase in heart rate in response to fire alarms

(Kuorinka & Korhonen, 1981), and fire suppression activities (Sothmann, Saupe, Jasenof & Blaney, 1992), while the third found that fire alarms had no significant effect on heart rates (Lim, Ong & Phoon, 1987).

Advances in technology and measurement devices allow for less invasive and cumbersome means of collecting this critical data. The aim of this cross-sectional study was to answer the following research questions: How does the heart rate at VT, and the heart rate at VO_2 max, compare to actual maximum heart rate during a 24 hour work shift? What activities are associated with actual maximum heart rate on duty? What is the average, and range, of METs during a 24-hour shift?

METHODS

This study estimates the on-duty energy demands of firefighters based on maximal exercise testing heart rates and direct VO_2max measurement. A cross-sectional study design was used to determine maximal heart rate and VO_2max, and on-duty heart rates (convertible to energy demands) with associated activities.

Setting and Sample

A medium-sized suburban fire department in the eastern region of the San Francisco Bay Area in northern California served as the setting. All male firefighters assigned to suppression duties were recruited; this included firefighters, firefighter/ paramedics, firefighter/engineers, firefighter/captains and battalion chiefs. All testing took place during a five week period between December, 2008 and January, 2009. Inclusion criteria required that each participant had successfully completed a WFI exam within the last nine months and achieved a minimum of 10 METs (VO_2max of 35 ml/kg/min), on either a sub-maximal (using the earlier equation), or maximal Gerkin (now WFI) treadmill protocol. Exclusion criteria included injury, illness or scheduling conflicts that precluded testing during the study period.

The study was conducted with approval of the University of California San Francisco Committee on Human Research. Signed informed consents were obtained from each participant. All testing was done while firefighters were on-duty with the approval of the department administration and union local.

Maximal exercise treadmill tests with direct VO_2max measurements were completed at an occupational health clinic where all previous WFI examinations for this fire department had been conducted. All treadmills were performed by a physician board certified in internal medicine and occupational medicine and a nurse practitioner experienced in exercise testing. On-duty Holter monitoring was conducted in the firefighter's assigned fire station and district.

Measurements

The measurements consisted of medical record abstraction of demographics, exercise testing results, direct measured VO_2max results, 24-hour Holter monitor results, and 24-hour activity logs.

Demographics. Age, rank, and years of fire service were obtained.

Maximal Exercise Treadmill with Direct VO_2 max Assessment

Maximal exercise treadmill tests using the WFI Protocol and direct VO_2max assessments were completed on all 83 participants. Tests, whether or not they surpassed estimated peak heart rates, were considered complete when the firefighter indicated volitional fatigue, or if terminated by the testing physician due to concerns about cardiopulmonary distress. The WFI Protocol, a modified ramp protocol (formerly the

Gerkin Protocol), is comprised of a 3-minute warm-up period at 3 mph – 0% grade, followed by fifteen one-minute stages. Stage 1 begins at 4.5 mph and 0% grade, the treadmill incline and speed increase alternately from stages 2 through 15; the grade increases by 2% and the speed by 0.5 mph each alternate stage.

After having height, weight and resting blood pressure assessed each participant received a resting ECG using the Welch-Allyn Schiller AT-10 6-Channel electrocardiograph/treadmill (San Diego, California) previously utilized during WFI examinations. Upon completion of the resting ECG the Mason-Likar lead configuration was modified to accommodate the maximal exercise treadmill (Froelicher & Myers, 2006). The participant was then fitted with the appropriate 2-way non-rebreathable mask (Hans-Rudolph, Inc., Shawnee, Kansas) to eliminate extraneous room air from affecting the interpretation of VO_2max. Measurement of participant VO_2max was achieved with the Cardio Coach CO_2^{TM} VO_2 Fitness Assessment System, Model 9001-RMR (Korr Medical Technologies, Salt Lake City, Utah).

The Cardio Coach CO_2^{TM} is an economical, portable metabolic testing device that is feasible for use in clinics and has been previously validated, particularly at VO_2max levels (Clinical Exercise Research Center Division of Biokinesiology and Physical Therapy at the School of Dentistry, 2009; Jensky, Vallejo, Ong, & Schroeder, 2005). The Cardio Coach CO_2 is a dual gas analyzer (O_2 and CO_2) that automatically calibrates to standard temperature and pressure, dry (STPD) at the beginning of each testing cycle. Heart rate was measured using the Polar T-31 heart monitor (Polar, Inc., Lake Success, NY) and reported with VO_2 (ml/min and ml/kg/min), VCO_2 (ml/min and ml/kg/min), VE/VO_2, VE/VCO_2, VE in L/min, FeO_2%, Fe CO_2%, and RER every 15 seconds. VT was detected using the ventilatory equivalents method (Ve/VO_2) (Korr Medical Technologies, 2009). Detailed procedures are available from the corresponding author.

24 Hour Holter Monitoring Using the H12+ Digital Holter Recorder

This fire department has a “48 hour on – 96 hour off” shift schedule. For 73 of the participants the maximal exercise treadmill with VO_2max assessment was completed on the first day of a 2-day tour, with the 24 hour Holter monitor being placed the evening of the first day and removed the evening of the second day of the shift. Ten of the 83 participants’ Holter recordings were delayed due to scheduling conflicts. The delay ranged from 3 to 12 days. All recordings were done during seventeen 24 hour periods over a span of five weeks from December 2008 to January 2009.

After completion of the clinic assessment the primary investigator went to each fire station and attached the Holter monitors (H12+ Digital Holter Recorder, Mortara, Inc., Milwaukee, Wisconsin). The H12+ Digital Holter Recorder records a 24-hour continuous 12 lead ECG and has been previously validated for clinical use (Extramiana, et al., 2006; Kolb, et al., 2001). Prior to placement each monitor was calibrated with the correct date and time as reported by the U.S. Naval Observatory (www.time.gov). Participating firefighters were instructed to shower and closely shave any remaining chest hair prior to the placement of the monitor. Leads were placed using modified Mason-Likar placement, with the RL lead placed on the central sternum between the second and third ribs, and the LL lead placed on the left hip (Mortara, Inc., Milwaukee, Wisconsin). The primary investigator checked all leads for placement, impedance, and rhythm prior to initiating the recording. Participants were asked to not shower during the next 24 hours, to perform their usual duties, and were provided with a 24-hour log form and asked to note their activities during the recording period. The primary investigator was available during the recording period via telephone and in person as necessary. Extra electrodes and instructions for removal and replacement of the monitor were left with each captain in the event that a shower, or some other event, interrupted the recording period. No firefighters terminated the monitors prior to the end of the recording period. Immediately prior to the end of the 24 hour recording period the primary investigator returned to the fire stations to remove the monitors.

Data from the maximal exercise treadmill test, VO_2max assessment and 24 hour Holter recording were aggregated by participant. VO_2 and the corresponding METs were determined by comparing the heart rates recorded during the 24 hour period to the every 15-second output from the Cardio Coach CO_2. For participants whose recorded 24 hour heart rate exceeded their heart rate at VO_2max the Holter tracing with the highest heart rate (and its corresponding event) was analyzed. For participants whose recorded 24 hour heart rate exceeded their heart rate at VT, but not their heart rate at VO_2max, the first Holter tracing with the heart rate exceeding their VT (and its corresponding event) noted during the 24 hour recording was analyzed.

Statistical Analyses

The differences between heart rate at VT and heart rate at VO_2max from the peak 24 hour monitored heart rate were calculated. Cross-tabulation was performed to determine the type and frequency of activities corresponding to excessive heart rates. Descriptive statistics were calculated to demonstrate the range and average of heart rates and METs expended during a normal fire shift. All statistical analyses were done with

SPSS version 15.0 (SPSS, Chicago, Illinois). Frequency and degree of heart rate changes, and rhythm recordings are reserved for future analysis.

RESULTS

There were 105 active suppression firefighters eligible for participation in the study. Of those, five were new hires who had not completed a WFI examination, leaving an eligible study population of 100. Six firefighters chose not to participate. Of the 94 choosing to participate 11 could not be scheduled for maximal exercise treadmills and VO_2 measurements due to injury, illness or scheduling conflicts resulting in an $n = 83$ for the study. Firefighters, firefighter/paramedics, firefighter/engineers, firefighter/captains and battalion chiefs were represented in this study.

The participants' ages ranged from 26 to 57, mean = 41.1 (± 6.9); 94% were Caucasian, and 6% were Hispanic or African-American. The years of firefighting experience ranged from 2 to 34, mean = 15.6 (±7.5 years). The average recording length was 23:27 ± 0:40. Initial descriptions of the minimum, maximum, and mean with standard deviation of heart rates from the Holter monitor recording are found in Table 1.

24 Hour Heart Rates Exceeding Heart Rate at VT and VO2max

Of the 83 participants, 57 (68.6%) increased their heart rates above their measured heart rate at VT; of those, 15 (18%) exceeded their measured heart rates at VT and VO_2max. The remaining 26 (31.3%) participants had heart rates that were below their measured heart rate at VT or VO_2max. The range of excessive beats above heart rate at VO_2max was 1 to 44, and the range of beats that exceeded heart rate at VT was 1 to 54.

Tables 2, 3 and 4 detail the activities as recorded on the 24 hour activity log as they correspond to the highest recorded heart rate.

There were 15 recorded episodes of bradycardia, defined as less than 50 beats per minute for 3 minutes or more. All fifteen episodes of bradycardia occurred during sleep.

Average METs and Heart Rates

Both heart rates and METs (Tables 5 and 6) demonstrated a substantial range from resting states to maximum heart rate and maximum METs during the 24 hour monitoring period. There were 15 participants who exceeded the maximal levels measured in clinical exercise testing. Heart rates were available from each participant at each level (resting, VT, VO_2max, and peak 24-hour). METs for the 15 participants who exceeded their heart rate at VO_2max could not be calculated (but by definition exceeded the measured METs at VO_2max) resulting in *n* = 57 for peak 24 hour METs; VT and VO_2max METs are detailed for the entire group (*n* = 83).

Discussion

The limitations of this study include the selection bias of the participants due to the narrow demographics of the group, and its cross-sectional design. The 83 days of monitoring represented here, although they encompass a five week period, are only a "snapshot" of the activities of a fire department, and are subject to the randomness of call demand. By definition the schedule on any given day in the fire service has many random elements. While there may be organized or planned activities (i.e. training, classroom, station duties, exercising) there is a strong likelihood that the schedule will be disrupted by calls. For this department those calls may be for fire suppression, medical aid, assistance with motor vehicle accidents, or investigating alarms. The results of this study reflect that randomness. The study was completed during the winter season which may have had an influence (positive or negative) on the type and frequency of calls, and the influence of hotter weather.

The strengths of this study lie in the number of participants, their range of age, rank and firefighting experience, and the consistent 23-24 hour on-duty monitoring periods. Use of the mask to measure VO_2max was different but not unknown to the participants as they routinely work with self-contained breathing apparatus. The 83 firefighters in this study represented 83% of the department members who met the inclusion criteria for the study (male, assigned to suppression, successfully completed the WFI exam in the previous nine months). An additional 11 firefighters consented to participate but did not due to injury, illness or scheduling conflicts. The ability to perform all testing components while on duty positively encouraged participation. There were no incentives offered for participation. All testing was completed using the same equipment and personnel, thus increasing consistency and inter-rater reliability.

This study represented the largest group of on-duty monitoring reported in many years. While the group was entirely male that is reflective of the fire service as a whole (Women in the Fire Service Inc., 2006), and represented the ages, years of service, range of fitness, and ranks commonly found in career fire departments. The distribution of activity was similar when comparing heart rates at VT, VO2max, and peak 24 hour rates.

We found that the activities, heart rate and METs ranges demonstrated that firefighters do approach and exceed maximum thresholds in the course of a normal shift, and may exceed levels observed during clinical exercise testing. If there is underlying, and perhaps undiagnosed or untreated cardiovascular disease, this elevates the risk of experiencing an on-duty cardiac event. The 15 participants who exceeded their heart rate at VO_2max represent the most significant risk, but the larger group (*n* = 57, which includes the previous 15) who exceeded their heart rate at VT are also of concern. Working for extended periods beyond VT initiates anaerobic metabolism, which is dramatically less efficient than aerobic metabolism, and can compromise cardiovascular function (Froelicher & Myers, 2006). The fact that 68.6% of the study population spent part of their normal shift at these elevated levels is remarkable. An additional 20.5% of the study group experienced a sustained episode of tachycardia (but remained below the VT and VO_2max thresholds) as well, resulting in 89.1% of the participants having elevated heart rates at some point during the 24 hour period. Continuous improvement of cardiovascular status is an appropriate goal for firefighters, and the WFI or similar program is a suitable approach for fire departments to embark on.

Conclusion

This study illustrated the range of energy demands experienced by a suburban career fire department during normal on-duty activities. The data presented here, especially when combined with the future analysis of heart rate variability, frequency and dimension of arrhythmias and their associated activities, will contribute to establishing safe working thresholds for career firefighters.

It is hoped that primary and specialty care providers who review this study will appreciate the extraordinary work demands required by firefighting and the potential for cardiac compromise to occur as part of day to day work. To insure the well-being of those who keep us safe it is imperative that health care providers provide and encourage early and aggressive interventions when cardiovascular risk factors develop and/or are diagnosed in firefighters.

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Table 1 - *24 Hour Recording Statistics, n = 83*

	Mean, SD	**Minimum**	**Maximum**
Number of QRS complexes	104,341 (± 9615.84)	78,499	131,179
Hours of Holter monitoring	23:27 (± 0:40)	18:50	24:00
Resting HR	65 (± 9.5)	42	91
Maximum 24 hour heart rate	162 (± 17.7)	106	196
Minimum 24 hour heart rate	44 (± 5.7)	30	64
Mean HR	75 (± 7.2)	61	94

Classroom/Station Activities712.25%

Table 2 – *Activity*, 24 Hour Heart Rate Greater than Heart Rate at Ventilatory Threshold (VT) and Maximal Exercise (VO_2max), n = 15*

Activity at 24 hour Maximum Heart Rate > Heart Rate at VT and VO_2max	**n**	**%**
Exercising	6	40.0
Performance Drills	5	33.3
Fire Suppression	3	20.0
Pack Test**	1	6.7

*-obtained from activity log
**-Pack Test –An assessment tool utilized by the United States Department of Agriculture to determine ability to do "arduous" work. It consists of carrying a 45 pound pack and covering three miles in 45 minutes on flat terrain (Sharkey, 1997).

Table 3 – *Activity*, 24 Hour Heart Rate Greater than Heart Rate at Ventilatory Threshold, n = 57*

Activity at 24 hour Maximum Heart Rate > Heart Rate at VT	**n*****	**%**
Exercising	15	26.3
Performance Drills	9	15.8
Fire Suppression/Overhaul	7	12.25
Pack Test**	6	10.5
Responding to Other Calls	13	22.9
Classroom/Station Activities	7	12.25

*-obtained from self-report activity log
**-Pack Test –An assessment tool utilized by the United States Department of Agriculture to determine ability to do "arduous" work. It consists of carrying a 45 pound pack and covering three miles in 45 minutes on flat terrain (Sharkey, 1997).
***-includes 15 who exceeded maximum heart rate (also shown in Table 2)

Table 4 – *Activity, 24 Hour Heart Rate Greater than Tachycardia*, n = 17*

Activity at 24 hour Maximal Heart Rate > Tachycardia	**n**	**%**
Exercising	11	64.7
Performance Drills	2	11.8
Pack Test	3	17.6
Responding to Other Calls	1	5.9

*Tachycardia defined by Holter monitor as 120 beats per minute for 3 minutes or longer.

Table 5 – *Description of Heart Rates (HR) at Rest, Ventilatory Threshold (VT), Maximal Exercise, and Maximum 24 Hour Monitoring n =83*

	Mean, SD	**Minimum**	**Maximum**
Resting HR	64 (± 9.5)	42	91
VT HR	150 (± 16.6)	102	183
Maximal Exercise HR	174 (± 10.8)	130	194
Maximum 24 hour HR	162 (± 17.7)	106	195

Table 6 – *Description of METs* at Ventilatory Threshold, Maximal Exercise, and Maximum 24 Hour Monitoring*

	n	**Mean, SD**	**Minimum**	**Maximum**
VT METs	83	9.5 (± 2.9)	3.9	16.9
Maximal Exercise METs	83	12.3 (± 2.6)	7.5	19.9
Maximum 24 Hour METs	68	10.9 (± 2.8)	4.8	17.0

METs* = METs calculated by VO_2 divided by 3.5.

CHAPTER SIX – EXECUTIVE SUMMARY AND CONCLUSION

Sudden cardiac death is the leading cause of on-duty death among firefighters. This loss of life often occurs earlier than in the general population and is at many levels, preventable. The specific purposes of this dissertation research are to define cardiovascular risk factors in career fire fighters as compared to the general population; determine the accuracy of VO_2max assessment methods in the WFI; and measure on-duty heart rates to determine the energy during work demands of firefighting.

The overall purpose of this dissertation is to synthesize the results from these areas to provide a clearer picture to researchers, providers, and fire service personnel of the demands and risks that may contribute to on-duty sudden cardiac death. This information can shape appropriate programs and interventions that reduce, or prevent, sudden cardiac death in this population in the future.

A review of the literature indicates that career firefighters in the United States are not at greater risk than the general population for all-cause mortality. There may have been a greater mortality risk to firefighters prior to the wide spread use of PPE. However, the HWE is less prominent in this population than one might expect given that career firefighters enter the fire service free of chronic disease, most notably diabetes.

The reduced HWE demonstrated in the literature may be, in part, due to the stress and extreme work demands of firefighting. The primary problem, however, appears to be that firefighters may succumb to the same epidemic of obesity, untreated hypertension, and/or hyperlipidemia as seen in the general population, and that those morbidities may reduce the benefit of the HWE.

Based on review of three modifiable risk factors (obesity, hypertension and hyperlipidemia) it appears that firefighters have risk profiles similar to the general population. They may be overweight; and have hypertension and hypercholesteremia that is often undetected and or under treated. The increasing incidence of obesity, and the under-diagnosis and or under-treatment of hypertension and hypercholesteremia in career firefighters are of the foremost concern. These factors may prove compromising in light of the significant work demands found in firefighting. They also offer opportunities for intervention.

The impact of demanding hard work with heavy gear on the cardiovascular system is repeatedly established in the literature. Efforts to define work energy demands of firefighting have focused on determining the metabolic equivalent (METs) levels required to safely carry out fire suppression duties. The ability to accurately assess physical fitness is critical. As sudden cardiac death is the leading cause of on-duty death among firefighters accurate determination of cardiopulmonary status is essential. This study compared four different methods of assessment.

The most objective method and "gold standard" is the direct measurement of VO_2max (Froelicher & Myers, 2006). Direct VO_2max measurements were used for comparison to the other three methods. Directly measured VO_2max and maximal exercise treadmill results indicate that the estimation equation utilized by the WFI maximal treadmill over-estimates VO_2max by an average of 1.16 METs.

Estimated maximal heart rates were, on average, 5 beats per minute higher than those measured during peak exercise. Heart rates are often used on the fire ground to determine if a firefighter can re-enter the fire scene. If a firefighter's fitness level is below optimal, or if they have underlying cardiovascular disease, this overestimation could lead to on-duty clearances that could prove compromising.

Concerns about over-estimation of the WFI sub-maximal exercise treadmill equation resulted in a revision in 2008 (IAFF, 2008). Directly measured VO_2max compared to 2009 sub-maximal estimates (based on the revised equation) found the two assessment methods in good agreement. The revised sub-maximal treadmill appears to provide a safe, non-invasive, objective measure of cardiopulmonary status.

In order to protect firefighters from compromising cardiac situations it is imperative that the results of testing be accurate, whether the test itself is being used for duty assignment, or as part of a comprehensive risk assessment. Providers who are responsible for making fitness-for-duty assessments should consider the inherent requirements of the job, any underlying cardiovascular risk factors, and the testing method utilized.

This dissertation represents the largest group (n = 83) of on-duty cardiac monitoring reported in many years (average length of monitoring = 23:27 hours ±:40). While the sample were entirely men this reflects of the fire service as a whole (Women in the Fire Service Inc., 2006). The study population represented the ages, years of service, range of fitness, and ranks commonly found in career fire departments. The distribution of activity was similar when comparing heart rates at VT, VO_2max, and peak 24 hour rates.

The analysis of heart rates in this population demonstrated that more excessive heart rates (>120 bpm) were found with training drills and exercising than in fire suppression or other call activity. This may be reflective of the call content and volume experienced during the study period.

The activities, heart rate and METs ranges demonstrated that firefighters do approach, and exceed, maximum thresholds in the course of a normal shift. If there is underlying, and perhaps undiagnosed or untreated cardiovascular disease, this elevates the risk of experiencing an on-duty cardiac event. Participants who exceeded their heart rate at VO_2max and represent the most significant risk, but those who exceeded their heart rate at VT which is also of concern. Working for extended periods beyond VT initiates anaerobic metabolism, which is dramatically less efficient than aerobic metabolism, and can compromise cardiovascular function (Froelicher & Myers, 2006).

In this study 89.1% of the participants had a monitored heart rate greater than 120 beats per minute at some point during the 24 hour monitoring period. Continuous improvement of cardiovascular status is an appropriate goal for firefighters, and the WFI or similar program is a suitable approach for fire departments to embark on. Appreciation of the work demands, when coupled with potential underlying cardiovascular disease, should be of concern to firefighters, fire service administrations, and to health providers.

Limitations

The limitations of this study include the selection bias of the participants due to the narrow demographics of the group, and its cross-sectional design. While there are no female firefighters in this sample this is similar to the national distribution that is 98.1%

male; therefore this study population is reflective of the national career fire service. The 83 days of monitoring represented here, although they encompass a five week period, are only “snapshot” of the activities of a fire department, and are subject to the randomness of call demand. The results of this study reflect that randomness. The study period included the winter holiday season and may have influenced fitness behaviors.

Strengths

The number of participants and their wide range of ages, experience and duty assignments contribute to the strength of the findings presented here. The ability to complete the cross-sectional data collection for the maximal exercise treadmill tests, VO_2max, and 24-hour monitoring within a five week period reduced potential confounders. For all the cross-sectional analyses there was sufficient sample size and the observed effect sizes (Cohen’s *d*) were medium to large. The 83 firefighters in this study represent 83% of the department members who met the inclusion criteria for the study (male, assigned to suppression, successfully completed the WFI exam in the previous nine months). The ability to perform all testing components while on duty positively encouraged participation. There were no incentives offered for participation. All testing was completed in the same facility using the same equipment and personnel, thus increasing consistency and inter-rater reliability.

An additional strength to this work is the participants’ relationship to the occupational health clinic. An eight year relationship delivering the WFI resulted in a substantial level of trust between the provider and the participants which positively encouraged participation. It is difficult to predict how much influence that relationship had on the outcomes, or how hard it would be to generate the same level of participation in an unknown study population.

Implications for Occupational Health Nursing

Occupational health nurses and nurse practitioners are uniquely positioned to address the issues raised by this research. They are in a position to counsel firefighters directly, as well as design programs within fire departments to assess risk, develop and implement intervention programs, evaluate the effects of interventions, and most importantly, convey the unique demands and risks of firefighting to community providers.

While not the direct focus of this study it makes intuitive sense that in addition to accurate cardiopulmonary capacity assessments attention be paid to underlying cardiovascular risk factors as well. Given the findings of major risk factors in firefighters, an argument can be made that early detection of risk, as well as ongoing surveillance of firefighters who are identified to have cardiovascular risks factors, is justified and deserves evaluation. The literature illustrates that modifiable risk factors are under-diagnosed and under-treated, and that the work demands are extreme. Areas of prime influence are nutrition and cardiovascular status (including education and access to healthy foods, healthy weight goals) (IAFF, 1999), and continued focus on heart healthy behaviors (appropriate use of PPE, smoking cessation, exercise). Programs targeted at appropriate risk identification and treatment, coupled with aerobic conditioning (such as the WFI), are an appropriate pathway to reducing the incidence of on-duty sudden cardiac death.

In designing such a program occupational health nurses need to be vigilant in implementation, execution and evaluation. Using prevention paradigms, such as McKinlay's "Upstream, Mid-stream, Downstream" model and other health promotion concepts will assist in all phases of program delivery and evaluation. McKinlay's model is best suited for the "macro-issues" (municipalities, administrations) whereas health promotion concepts may be more helpful with the "micro-issues" encountered at the individual level. Obesity, hypertension, hypercholesteremia, and aerobic conditioning all require significant lifestyle changes on the part of the participant, and commitment by occupational health nurses to utilize health promotion concepts to address barriers to success. It is clear that firefighters need to take personal responsibility for modifiable risk factors – however, that responsibility must be facilitated by a supportive environment and colleagues. When developing programs for the career fire service occupational health nurses need to be sensitive to the fact that the fire station, and crew, represent a second "family" for firefighters, with all of the inherent dynamics of group living and family life. Additionally, occupational health nurses need to acknowledge the historical friction and lack of trust that often exists between fire department administrations and suppression staff. It is critical that occupational health nurses protect firefighter confidentiality while implementing and administering programs that demonstrate improvement in risk factors to administrators.

An equally important role for occupational health nurses and nurse practitioners is the facilitation of education and communication. In reviewing the literature the percent of under-diagnosed and under-treated hypertension and hypercholesteremia is alarming. It is unknown if that deficit is related to lack of understanding by the firefighter or the primary care provider of the risks, or lack of communication between the firefighter and the primary care provider regarding medical surveillance findings or follow-up care (i.e. the firefighter never followed up with their primary care provider, or perhaps the primary care provider is not familiar with the stressors of firefighting).

Occupational health nurse practitioners are uniquely positioned to initiate treatment for under-treated risk factors and ensure appropriate transition and communication to the primary care provider. Early detection of cardiovascular risk factors and aggressive interventions should be the goal of all occupational health professionals when designing and implementing surveillance or wellness programs for the fire service.

Conclusion

Reducing the incidence of sudden cardiac death among career firefighters is an attainable goal. It is clear that there are multi-factorial causes that contribute to sudden cardiac death – ranging from modifiable personal cardiovascular risk factors to non-modifiable extremely arduous work demands in compromising environments.

This study illustrated the substantial range of energy demands experienced by a suburban career fire department during normal on-duty activities. This study also identified those assessment tools that most accurately estimate firefighter cardiopulmonary capacity. The data presented here, especially when combined with the future analysis of heart rate variability, frequency and dimension of arrhythmias and associated firefighter activity, will contribute to establishing safe working thresholds for career firefighters.

It is hoped that firefighters, health care providers, municipalities, and fire service administrators can appreciate the extraordinary work demands required by firefighting, and the potential cardiac compromise those demands represent. Firefighters must be encouraged to take personal responsibility in making necessary life-style changes to reduce their risk. To insure the well-being of those who keep us safe it is imperative that health care providers initiate and encourage early and aggressive interventions when cardiovascular risk factors develop and/or are diagnosed in firefighters. Municipalities and fire service administrators need to understand that the aim of prevention is to monitor cardiovascular risk status, encourage healthy behaviors, and implement timely and appropriate interventions, in order to reduce morbidity and mortality in firefighters. These efforts will be beneficial to firefighters, their families, the fire service, and the communities they serve.

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APPENDIX 1 - CHR APPROVAL

Committee on Human Research

Project Summary Sheet

CHR: H59198-32945-01A

Study Title

Cardiovascular Risk Factors in Career Firefighters

Principal Investigator

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Human Subjects Training

The PI and Co-PI must complete the UCSF online training course: Protecting Human Research Subjects

Name	Last Completed
Hong, Oisaeng	
Drew-Nord, Dana C.	

Review Details

Approval Number	Status	Received	Reviewed	Approved	Expires
H59198-32945-01A	Approved	3/5/2009 12:(	3/20/2009 12:	3/20/2009 12	10/3/2009]
H59198-32945-01	Approved Following Response	6/26/2008 12	8/26/2008 12:	10/3/2008 12	10/3/2009]

Attachments: Expanded Consent Form, Dated 3/5/09
Consent Form, Dated 9/24/08

APPENDIX 2 – HOLTER MONITOR ACTIVITY LOG

Holter Monitor Activity Log

TIME	CODE	COMMENT
0800-0900		
0900-1000		
1000-1100		
1100-1200		
1200-1300		
1300-1400		
1400-1500		
1500-1600		
1600-1700		
1700-1800		
1800-1900		
1900-2000		
2000-2100		
2100-2200		
2200-2300		
2300-2400		
2400-0100		
0100-0200		
0200-0300		
0300-0400		
0400-0500		
0500-0600		
0600-0700		
0700-0800		
0800-0900		

CODES - A – Call
B – Physical Training
C – Station Duties
D – OSHA Safety Nap/Sleep
E – Meals
F – Rest, relaxation

APPENDIX 3 – MAXIMAL EXERCISE TEST PROCEDURE

1. Each firefighter was instructed to arrive with gym clothes and running shoes.
2. Height and weight (without shoes) was measured.
3. Resting blood pressure was obtained.
4. The firefighter assumed a supine position on the examining table and excessive chest and back hair was removed with electric clippers.
5. Electrode placement areas were cleansed with isopropyl alcohol and gently abraded with a very fine grit abrasion pad.
6. Silver chloride gel electrodes were placed in the standard resting electrocardiogram configuration and the electrocardiograph leads were attached.
7. A resting electrocardiogram was obtained.
8. The firefighter was instructed to assume a standing position.
9. The limb leads (RA, LA, RL, LL) were repositioned using fresh electrodes in the following manner:
    a. RA was moved from the right wrist to the upper right chest wall inferior to the right clavicle and medial to the right humeral head.
    b. LA was moved from the left wrist to the upper left chest wall inferior to the left clavicle and medial to the right humeral head.
    c. RL was moved from the right ankle to the lower back between L1 and L2.
    d. LL was moved from the left ankle to the left iliac crest.

e. Leads V_1-V_6 were left in their original placement.

10. All leads and electrodes were secured with a padded foam belt and Velcro strips.

Please see the procedure for the VO_2 measurement (Appendix 4) as both tests are concurrent at this point.

11. A standing electrocardiogram was obtained.
12. The firefighter was instructed to place their feet on the rails of the treadmill until it was in motion.
13. Firefighters were instructed to use a “thumbs up” or “thumbs down” response to questions as the VO_2 mask inhibits conversation; and how to stop the treadmill if necessary by using the large red “stop” emergency button.
14. The treadmill protocol was initiated with an initial 3 minute warm-up stage of 3 mph, 0% grade and the firefighter was instructed to begin walking on the treadmill.
15. Stages 1-15 each lasted for 1 minute. Table 4 defines the speed and elevation gradients. Firefighters were queried at each stage to determine degree of difficulty and ability to progress.
16. The maximal exercise treadmill was terminated when the firefighter indicated volitional fatigue or by physician judgment.
17. A 3 minute cool down (1.5 mph, 0% grade) was conducted.
18. All leads and electrodes were removed and the firefighter was provided a clean towel to remove excess perspiration.

19. The completed maximal stress treadmill report was placed in the firefighter's study chart.

Table 4. *Time, Speed and Gradient for WFI Exercise Treadmill*

Phase	Time (minutes)	Speed – mph	Grade
Warm-up	0:00 – 3:00	3.0	0
Stage 1	3:01 – 4:00	4.5	0
Stage 2	4:01 – 5:00	4.5	2
Stage 3	5:01 – 6:00	5.0	2
Stage 4	6:01 – 7:00	5.0	4
Stage 5	7:01 – 8:00	5.5	4
Stage 6	8:01 – 9:00	5.5	6
Stage 7	9:01 – 10:00	6.0	6
Stage 8	10:01 – 11:00	6.0	8
Stage 9	11:01 – 12:00	6.5	8
Stage 10	12:01 – 13:00	6.5	10
Stage 11	13.01 – 14:00	7.0	10
Stage 12	14:01 – 15:00	7.0	12
Stage 13	15:01 – 16:00	7.5	12
Stage 14	16:01 – 17:00	7.5	14
Stage 15	17:01 – 18:00	8.0	14
Recovery	0:00 – 3:00	3.0	0

APPENDIX 4 – VO_2MAX ASSESSMENT PROCEDURE

VO_2 Measurement.

1. At the conclusion of the resting electrocardiogram and prior to obtaining the standing electrocardiogram the firefighter was instructed to sit in a chair.
2. The appropriate sized two-way (Hans-Rudolph, Inc., Shawnee, Kansas) non-rebreathable mask was fitted with a secure mesh headpiece.
3. The breathing valves were obstructed and the firefighter was instructed to take a deep breath in and exhale a deep breath to ensure that the seal was complete. Adjustments were made as necessary to ensure a complete seal.
4. The Polar T-31 heart rate monitor chest strap was placed with electrode gel to facilitate transmission immediately below the treadmill V_1-V_6 electrodes.
5. The firefighter's age, height and weight were entered into the Cardio Coach CO_2™ VO_2 Fitness Assessment System, Model 9001-RMR (Korr Medical Technologies, Salt Lake City, Utah).
6. The Cardio Coach CO_2™ was calibrated to STPD prior to beginning each test.
7. At the conclusion of calibration the breathing hose was connected between the measuring unit and the non-rebreathable mask.
8. A standing electrocardiogram was obtained *(see step 11 in the maximal exercise treadmill protocol, Appendix 3).*
9. The VO_2 measurement was initiated simultaneously with the initiation of the maximal exercise treadmill.

10. VO_2 was measured continuously throughout the maximal stress treadmill. The heart rate calculated and transmitted by the Polar T-31 heart rate monitor was compared every 30 seconds to the heart rate recorded by the Welch-Allyn Schiller AT-10 6-Channel electrocardiograph.
11. At the point the firefighter indicated volitional fatigue a 3 minute cool down was initiated and marked as “Recovery” on the Cardio Coach CO_2^{TM} recording unit.
12. At the conclusion of the cool down the non-rebreathable mask, breathing tube and heart rate monitor chest strap were removed.
13. The Cardio Coach CO_2^{TM} report was placed in the firefighter’s study chart.
14. At the conclusion of every test the non-rebreathable mask and heart rate monitor chest strap were thoroughly disinfected two times with Cavicide wipes. The breathing tubes, heart monitor chest straps and mesh headpieces (5 of each in use) were alternated with each test to allow for drying time and laundered (if appropriate) at the end of every testing day.

APPENDIX 5 – 24 HOUR HOLTER PROCEDURE

24 Hour Monitoring.

1. At the conclusion of the simultaneous treadmill/VO_2 measurement the firefighter was instructed to take a shower prior to the planned placement of the 24 hour monitor in the early evening of the same day.
2. To facilitate their own comfort firefighters were instructed to closely shave all electrode areas.
3. Prior to placement each H12+ Digital Holter Recorder (Mortara, Inc., Milwaukee, Wisconsin) was calibrated to the correct time and date as reported by the U.S. Naval Observatory (www.time.gov).
4. Each participant's ID number was entered into the recorder.
5. The dissertation investigator arrived at the designated fire station in the early evening of the test day.
6. The firefighter was asked to remove his shirt and the electrode areas were again wiped down with isopropyl alcohol.
7. Fresh silver chloride electrodes, with the H12+ Digital Holter Recorder leads attached, were placed in the same configuration as the stress treadmill with the exception of the RL limb lead. The RL limb lead was placed centrally on the sternum at the level of the third rib.
8. The H12+ Digital Holter Recorder lead cable was attached to the recorder.
9. Impedance of each lead was checked on the monitor and lead/electrode combinations were re-positioned as necessary to maximize impedance.

10. The electrocardiogram for each lead was checked for rhythm and reliability.
11. The 24 hour recording was initiated.
12. The firefighter was asked to lie down on the floor on their back and a supine electrocardiogram was marked as an event.
13. The firefighter was asked to roll onto their left side and a lateral recumbent electrocardiogram was marked as an event.
14. A sleeveless ribbed cotton T-shirt (one size smaller than normally worn) was placed over the leads and electrodes.
15. An adjustable elastic belt and carrying pouch was placed to secure the monitor.
16. Each firefighter was given an activity log to keep for the next 24 hours (Appendix 4).
17. Each firefighter was instructed to keep to their normal routine during the next 24 hours with the exception of taking a shower.
18. In the event that removing the monitor to shower or for any other purpose became necessary extra electrodes and instructions were left with each captain to facilitate the removal and replacement of the monitor.
19. The dissertation investigator was available during the recording period via telephone and in person as necessary.
20. At the end of the 24 hour monitoring period the dissertation investigator returned to the fire station and terminated the recording.

21. All monitors were disconnected and returned to the clinic to download the data.
22. Each recording was transferred from the compact flash card to a password protected computer with the H12+ Digital Holter Recorder software for analysis. At the end of the transfer the compact flash card was erased.

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Dana C. Drew-Nord   *June 12, 2009*