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NIOSH
Fire Fighter Fatality Investigation
and Prevention Program

Death in the line of duty...

A Summary of a NIOSH fire fighter fatality investigation *July 6, 2005*

Probationary Fire Fighter Suffers Sudden Cardiac Death During Maze Drill - Connecticut

SUMMARY

On March 13, 2004, a 38-year-old male volunteer probationary Fire Fighter (FF) suddenly collapsed while performing a maze drill. Teammates extricated the FF from the maze, removed his self-contained breathing apparatus (SCBA), and found him in cardiac arrest. They began cardiopulmonary resuscitation (CPR) while an ambulance was summoned. Despite CPR and advanced life support (ALS) provided by teammates, police, and ambulance personnel, the FF died. The death certificate and the autopsy, completed by the Chief Medical Examiner, listed "sudden death associated with rheumatic heart disease" as the cause of death. NIOSH investigators concluded the physical stress of fire suppression training and his underlying valvular heart disease contributed to this fire fighter's sudden cardiac death.

The following recommendations are preventive measures recommended by other fire service groups to reduce the risk of on-the-job heart attacks and sudden cardiac arrest among fire fighters.

Ensure that fire fighters are cleared for duty by a physician knowledgeable about the physical demands of fire fighting.

Perform a pre-placement and an annual physical performance (physical ability) evaluation for fire fighters to ensure they are physically capable of performing the essential job tasks of structural fire fighting.

Phase in a mandatory wellness/fitness program for fire fighters to reduce risk factors for cardiovascular disease and improve cardiovascular capacity.

Conduct exercise stress tests (EST) for fire fighters with two or more risk factors for coronary artery disease (CAD).

INTRODUCTION AND METHODS

On March 13, 2004, a 38-year-old male probationary FF collapsed during a SCBA maze drill. Despite CPR and ALS provided by teammates, police, and ambulance personnel, the FF died. NIOSH was notified of this fatality on March 15, 2004, by the United States Fire Administration. NIOSH contacted the affected Fire Department (FD) on March 24, 2004, to obtain further information, and on July 29, 2004, to initiate the investigation. On August 23, 2004, a Safety and Occupational Health Specialist from the NIOSH Fire Fighter Fatality Investigation Team and an Industrial Hygienist from the NIOSH New England Field Office traveled to Connecticut to conduct an on-site investigation of the incident.

During the investigation NIOSH personnel met and/or interviewed the following people:

- Fire Chief
- Fire Marshal
- Chief of the local Fire Chief's Association
- Deputy Police Chief of the town where the incident occurred
- FF's crew members
- Fire School instructors
- FF's family

During the site-visit NIOSH personnel reviewed the following records:

- FD policies and operating guidelines
- FD training records
- FD annual report for 2003
- Fire School incident report
- Police incident report
- FD physical examination protocols
- Ambulance records
- Death certificate
- Autopsy report

INVESTIGATIVE RESULTS

Incident. On March 13, 2004, the FF arrived at his fire station at approximately 0730 hours. After two additional fire fighters arrived, the three drove a FD apparatus to the neighboring town to attend Fire Fighter 1 (FF1) training. The class began at 0830 hours and consisted of 30 fire fighters supervised by six instructors. The planned activities for the day included:

- 45-second drill (donning SCBA, protective hood, helmet, and gloves within 45 seconds)
- Walk tower with mask off (climbing three flights of stairs while wearing full protective clothing [turnout gear, helmet, and gloves] and SCBA without mask)
- Walk tower with mask on (climbing three flights of stairs while wearing full protective clothing and SCBA with mask on but breathing ambient air)
- Walk tower with mask on, air on, and theatrical smoke (climbing three flights of stairs while wearing full protective clothing and SCBA with mask on and breathing bottle air, with visibility reduced by theatrical smoke)
- Use of cascade system (refilling SCBA bottles)
- Maze (complete at least two trips through while wearing full protective clothing and SCBA)
- Wood chop breathing conservation (while wearing full protective clothing and SCBA with mask on and breathing SCBA air)
- Barrel drill (make contact with hose rolls placed throughout an area while wearing full protective clothing and SCBA with mask on and breathing SCBA air with vision obscured)
- Reduced profile (crawling through a restricted opening while wearing full protective clothing and SCBA, on-air, by partially or totally removing the SCBA, but not the mask)

After completing classroom activities (roll call, quiz, practical skills, etc.), the entire group performed the 45-second drill, walk tower with mask off, walk tower with mask on, and the walk tower with theatrical smoke. The class then divided into five groups, with six fire fighters in each group. The FF's group (Group 5) participated in the cascade system station and the reduced profile prior to lunch break.

After lunch, at approximately 1250 hours, Group 5 participated in the wood chop breathing conservation exercise. After a 25-minute break, Group 5 proceeded to the maze station at approximately 1330 hours.

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A trailer was converted into a maze by building restricted passages throughout its right side. The passages were constructed of plywood and lumber, and contained several openings that allowed students to move through the three levels. A ladder connected the three levels. Obstacles were placed throughout the maze and required the students to work together to exit the passage. Access doors opened to all levels of the passages, affording instructors opportunities to view the students' performance and to contact the students if necessary. During each maze evolution, students worked in teams of two and followed a 1½-inch hoseline in a low light condition into and out of the maze.

Prior to the training, the two instructors reviewed the maze procedures and safety information. Although this was the first time the FF had performed the maze training, he had been briefed on the safety aspects. The FF wore full bunker gear and SCBA (not breathing cylinder air) weighing approximately 45 pounds. He and a partner completed one evolution in the maze, which required following a hoseline through the first level. After exiting the maze, the FF told an instructor that he was okay and needed to change SCBA bottles.

Successive trips through the maze required proceeding through additional levels. Two other fire fighters entered the maze. After changing his SCBA bottle, the FF and his partner entered the maze on the second level for their next trip through. As all the fire fighters approached the ladder inside the maze, a low-air alarm sounded (probably the FF's). The first two fire fighters continued down the third level to the trap doors. The FF's partner then came to the trap door and the instructor explained to him how to go through it. The partner went through the door and waited for the FF to come down. The FF came to the trap door and the instructor asked him if he was okay. The FF stated that he was running out of air and the instructor advised him to disconnect his SCBA regulator and to breathe normal air. The FF stated he was okay and then continued down through the trap door to the first level. He rolled over onto his stomach and proceeded down the first level with his partner.

When the two reached the end of the first level, the partner came out from under the ladder. The instructor shone a flashlight onto the FF, who appeared to be looking for his partner. The instructor asked the FF if he was okay and the FF said, "No, I need to get out." He did not indicate symptoms of claustrophobia or angina. The instructor advised the partner to assist the FF. As the FF got approximately halfway through the maze, it appeared that he was stuck. Another instructor assisted the FF by pulling on his waist strap and it appeared the FF was unable to move. The first instructor reached down to assist in removing the FF. The trailer light was turned on, the FF was pulled out from underneath the stairs, was rolled over, and his mask taken off.

The FF was assessed and found unresponsive, not breathing, and pulseless. The FF's partner went to call 911 while instructors removed the FF's gear and other fire fighters continued assessing the FF. Medical equipment was obtained as additional teammates and instructors arrived. CPR was begun, an oral airway was inserted, and oxygen administered via bag-valve-mask.

The call to 911 was received at 1439 hours and a police officer, a paramedic, and an ambulance were dispatched. The paramedic unit arrived at 1445 hours. Assessment of the FF revealed he was unresponsive, not breathing, and pulseless with CPR in progress. A cardiac monitor was attached to the FF and revealed asystole (no heart beat). The FF was intubated and an intravenous (IV) line was attempted, but was not successful. A second attempt to establish an IV was success-

ful and cardiac resuscitation medications were administered with no change in heart rhythm. The ambulance arrived at 1451 hours. The FF was placed onto a backboard, onto a stretcher, and into the ambulance, departing the scene at 1457 hours en route to the hospital. En route, CPR and ALS procedures were continued until 1508 hours when the ambulance arrived at the hospital emergency department (ED). Inside the ED, ALS continued without improving the FF's status. He was pronounced dead at 1535 hours, and resuscitation attempts were discontinued.

Medical Findings. The death certificate and the autopsy, completed by the Medical Examiner, listed "sudden death associated with rheumatic heart disease" as the immediate cause of death. Pertinent findings from the autopsy, performed on March 15, 2004, included the following:

Valvular Heart Disease

Mitral valves thickened and fusion of the chordae tendineae" (strong cords of fibrous tissue fused together resulting in thickening and shortening of the mitral valve cusps)

Aortic valve fusion of the right and left cusps

Normal heart size (380 grams), yet mild left atrial enlargement and dilatation

No significant coronary artery disease and no recent or remote evidence of a heart attack

Drug, alcohol, and carbon monoxide tests were negative

Microscopic Findings. The Medical Examiner listed some electron microscopy "findings suggestive of a mitochondrial myopathy."

According to the FF's family, the FF was born with a heart murmur. An echocardiogram performed in October 1997 to evaluate atypical chest pain revealed a probable bicuspid aortic valve with mild thickening, 1+ mitral regurgitation, 1+ aortic insufficiency, and a normal left ventricular ejection fraction of 61%. The FF was diagnosed with severe sleep apnea in November 2002 and prescribed a continuous positive airway pressure (CPAP) mask. A routine physical examination in May 2003 revealed the FF was having some intermittent chest pain, not always associated with exertion. Laboratory tests revealed a mildly elevated blood cholesterol level of 218 milligrams per deciliter (mg/dL)(normal 150-200 mg/dL) and total cholesterol/HDL ratio of 4.6 (normal). Due to chest pain symptoms, he was evaluated for ischemic coronary artery disease via an EKG and an imaging exercise stress test. The EKG showed non-specific ST-T wave changes. The EST was conducted via the Bruce protocol. The FF exercised for 7 minutes, 30 seconds (Stage III) reaching 9.5 metabolic equivalents (METS) before stopping due to shortness of breath and fatigue. He reached 77% of his maximal heart rate. The tracing and imaging studies revealed no evidence of ischemia or infarction, a normal wall motion, normal wall thickening, and a normal ejection fraction of 61%. However, because the FF was unable to reach his target heart rate, the EST was considered "indeterminate." At his pre-placement physical examination in November 2003, the FF weighed 233 pounds, had a blood pressure of 128/74 millimeters of mercury (mmHg), and was cleared for fire fighting duty.

DESCRIPTION OF THE FIRE DEPARTMENT

At the time of the NIOSH investigation, this volunteer FD consisted of 62 uniformed personnel. The FD served a population of 9,050 in an area of 14.3 square miles. There is one fire station.

In 2003, the FD responded to 717 calls: 3 structure fires, 1 brush fire, 5 car fires, 60 flex alarms, 90 vehicle accidents, 444 medical calls, 14 carbon monoxide alarms, and 100 other calls.

Training. The FD requires all new fire fighter applicants to meet with the executive committee, pass a physical examination, pass a criminal background check, and pass a vote by the membership prior to being accepted as a probationary fire fighter. The newly accepted fire fighter is on probation for 1 year and must achieve FF1 status within that year. Training occurs at regional State fire schools and in-house. In-house training occurs every Monday morning and Thursday evening. During the probationary first year, the fire fighter is not allowed to fight interior structure fires.

State fire fighter certification is voluntary. There is no mandatory annual refresher training. The FF was taking FF1 training and had been a member of the FD for 31 days.

Pre-placement Medical Evaluations. The FD currently requires a pre-placement medical evaluation for all fire fighter candidates. Components of the evaluation include:

- A complete medical history
- Physical examination
- Vital signs
- Vision screening
- Hearing assessment (whisper test)
- Blood analysis: lipid panel
  complete blood count
- Urine dipstick
- Chest x-ray
- Resting electrocardiogram (EKG)
- Hepatitis screening (Hepatitis B)
- Tuberculosis (TB) skin test
- Pulmonary function test (spirometry)
- Exercise stress test if over the age of 40 (Bruce protocol)[1]

These evaluations are performed by a contract clinic hired by the FD, who then makes a decision regarding medical clearance for fire fighting duties. This decision is forwarded to the Safety Officer and Fire Chief.

Periodic Medical Evaluations. Annual medical evaluations are required by this FD. The components are the same as the pre-placement evaluation. Medical clearance for respirator use is required annually.

FD members injured at work must be evaluated by their primary care physician. The physician forwards a recommendation regarding "return to work" to the local worker's compensation physician, and to the Fire Chief, who makes the final determination.

Fitness/Wellness Programs. Exercise (strength and aerobic) equipment is located in the fire station. Voluntary wellness/fitness programs are in place for the FD. Health/wellness maintenance information is available from the contract clinic. No physical ability tests are performed.

DISCUSSION

Coronary Artery Disease (CAD) and the Pathophysiology of Sudden Cardiac Death.

Acute rheumatic fever is a group A beta-hemolytic streptococci infection. In some instances an autoimmune reaction triggered by this organism causes the body's immune system to attack the heart muscle. This is known as rheumatic heart disease (RHD).[2,3] In most published series, between 40% and 60% of patients with acute rheumatic fever have evidence of RHD, which

is characterized by one or more of the following: sinus tachycardia, the murmur of mitral regurgitation, an S3 gallop, a pericardial friction rub, and cardiomegaly.[3] There was no definitive evidence of a myocarditis during this FF's autopsy.

Healing of the rheumatic valvulitis may cause fibrous thickening and adhesion, resulting in the most serious complication of rheumatic fever, valvular stenosis and/or regurgitation. The mitral valve is involved most frequently, followed by the aortic valve.[3] In rheumatic stenosis the valve leaflets are diffusely thickened by fibrous tissue and/or calcific deposits. The mitral commissures fuse, the chordae tendineae fuse and shorten, and the valvular cusps become rigid. These changes (seen at the FF's autopsy) lead to narrowing at the apex of the funnel-shaped valve.[4,5]

The circulatory system's response to mitral obstruction ranges from a normal cardiac output and a high left atrioventricular pressure gradient to a markedly reduced cardiac output and low transvalvular pressure gradient. In most patients with moderate mitral stenosis (MS), the cardiac output is normal or almost so at rest but rises subnormally during exertion.[4] When valvular obstruction is mild, the physical signs of mitral stenosis may be present without symptoms. However, even in patients whose mitral orifices are large enough to accommodate a normal blood flow with only mild elevations of left atrial pressure, marked elevations of this pressure leading to dyspnea and cough may be precipitated by severe exertion, excitement, etc.[4] An increase in heart rate shortens diastole proportionately more than systole and diminishes the time available for blood flow across the mitral valve.[5] Therefore, at any given level of cardiac output, tachycardia augments the transmitral valvular pressure gradient and elevates left atrial pressure further. This explains the sudden occurrence of dyspnea and pulmonary edema in previously asymptomatic patients with MS who develop atrial fibrillation with a rapid ventricular rate. In patients with mild to moderate MS without elevated pulmonary vascular resistance, pulmonary arterial pressure may be normal or only minimally elevated at rest but rises during exercise. A greater elevation of pulmonary arterial pressure represents a serious impedance to emptying of the right ventricle. A small percentage, perhaps 15%, of patients with MS experience chest discomfort indistinguishable from angina pectoris.[5] This symptom may be caused by severe right ventricular hypertension secondary to the pulmonary vascular disease or by concomitant coronary atherosclerosis. In many patients, however, a satisfactory explanation for the chest pain cannot be uncovered even after complete hemodynamic and angiographic studies.[5] Asymptomatic patients with moderate MS should be re-evaluated yearly. Heavy exertion is contraindicated in symptomatic patients.[5]

In temperate climates the latent period between the initial attack of rheumatic carditis (in the increasingly rare circumstances in which a history of an attack can be elicited) and the development of symptoms due to mitral stenosis is generally about two decades; most patients begin to experience disability in the fourth decade.[4]

Aortic valve stenosis, also called chronic rheumatic aortic valve disease with stenosis and calcific aortic stenosis, is aortic stenosis (AS) resulting from repeated attacks of acute rheumatic fever.[5,6] It is usually associated with mitral valvular disease caused by healed rheumatic valvulitis. Aortic stenosis occurs in about one fourth of all patients with chronic valvular heart disease; approximately 80% of adult patients with symptomatic valvular aortic stenosis are male.[4] Aortic stenosis in adults may be congenital in origin, it may be secondary to rheumatic inflammation of the aortic valve, or it may be due to degenerative calcification of the aortic cusps of unknown cause.[4]

The congenitally affected valve may already be stenotic at birth and may become progressively more fibrotic, calcified, and stenotic. In other cases the valve may be congenitally deformed, usually bicuspid, without serious narrowing of the aortic orifice during childhood.[4] Rheumatic aortic stenosis is almost always associated with rheumatic involvement of the mitral valve.[4] Although the cardiac output at rest is within normal limits in the majority of patients with severe AS, it often fails to rise normally during exertion.[5] In contrast to MS, which leads to symptoms almost immediately after its development, patients with severe AS may be asymptomatic for many years despite the presence of severe obstruction. Once patients with AS develop angina pectoris or syncope, the average survival is 1 to 3 years. Because of the gradual increase in the severity of obstruction, noninvasive assessment of this finding by Doppler echocardiography should be carried out at intervals. In patients with mild obstruction, this measurement should be repeated every 2 years.[5] According to medical records obtained by NIOSH, this FF's last echocardiogram was conducted in 1997.

Multivalvular disease is caused most frequently by rheumatic fever, and various clinical and hemodynamic syndromes can be produced by different combinations of valvular abnormalities.[5] In patients with multivalvular disease, the clinical manifestations depend on the relative severities of each of the lesions. When the valvular abnormalities are of approximately equal severity, clinical manifestations produced by the more proximal (upstream) of the two valvular lesions are generally more prominent than those produced by the distal lesion. In patients with multivalvular disease, the relative severity of each lesion may be difficult to estimate by clinical examination and noninvasive techniques because one lesion may mask the manifestations of the other. The left ventricle of a patient with MS and AS is usually small, stiff, and hypertrophied. The cardiac output tends to be reduced more than in patients with isolated AS.[5] Mitral valve disruption and valvular aortic stenosis as well as extreme physical activity have been linked with sudden cardiac death.[7]

Firefighting is widely acknowledged to be one of the most physically demanding and hazardous of all civilian occupations.[8] Firefighting activities are strenuous and often require fire fighters to work at near maximal heart rates for long periods. The increase in heart rate has been shown to begin with responding to the initial alarm and persist through the course of fire suppression activities.[9-11] Even when energy costs are moderate (as measured by oxygen consumption) and work is performed in a thermoneutral environment, heart rates may be high (over 170 beats per minute) owing to the insulative properties of the personal protective clothing.[12] Epidemiologic studies have found that heavy physical exertion sometimes immediately precedes and triggers the onset of acute heart attacks.[13-16] The FF, while wearing full turnout gear, performed the 45-second drill, walk tower off-mask, walk tower on-mask, the walk tower on-mask with theatrical smoke, the reduced profile, the wood chop breathing conservation station for 2.5 minutes, one complete trip through the maze, and nearly a second complete trip. This is considered a very heavy level of physical exertion.[17,18] The NIOSH investigators concluded the physical stress of training and his underlying mitral stenosis contributed to this fire fighter's sudden death.

Occupational Medical Standards for Structural Fire Fighters. NFPA 1582, *Standard on Comprehensive Occupational Medical Program for Fire Departments*, considers mitral stenosis a Category B condition (a medical condition that,

based on its severity or degree, could preclude a person from performing as a member in a training or emergency operational environment by presenting a significant risk to the safety and health of the person or others). The condition is acceptable if the FF's heart rhythm is in sinus rhythm and the stenosis is mild (e.g., valve area is > 1.5 centimeters squared [cm^2] or pulmonary artery systolic pressure is < 35 mmHg).[19] NFPA 1582 also considers aortic stenosis a Category B condition; acceptable if the condition is "mild," defined as an aortic valvular pressure gradient < 20 mmHg.[19] Medical records obtained by NIOSH suggested the FF never received any test to measure his aortic valve pressure gradient.

NFPA 1582 also considers sleep apnea (central or obstructive) a Category B condition for candidates. This FF was diagnosed with severe sleep apnea in November 2002.

RECOMMENDATIONS

The following recommendations are preventive measures recommended by other fire service groups to reduce the risk of on-the-job heart attacks and sudden cardiac arrest among fire fighters.

Recommendation #1: Ensure that fire fighters are cleared for duty by a physician knowledgeable about the physical demands of fire fighting.

Physicians providing input regarding medical clearance for fire-fighting duties should be knowledgeable about the physical demands of fire fighting and familiar with the consensus guidelines published in NFPA 1582. Frequently, private physicians are not familiar with a member's job duties or with guidance documents such as NFPA 1582. To ensure physicians are aware of these guidelines, we recommend that the FD provide the contract and private physicians of its members with a copy of NFPA 1582. In addition, we recommend the FD carefully evaluate the opinion of the member's private physician regarding return to work. This decision requires knowledge not only of the member's medical condition but also of the member's job duties. Lastly, we recommend that all return-to-work clearances be reviewed by a FD contracted physician. Thus, the final decision regarding medical clearance for return to work lies with the FD with input from many sources including the employee's private physician. At the time of this report, the FD has implemented this recommendation.

Recommendation #2: Perform a pre-placement and an annual physical performance (physical ability) evaluation for ALL fire fighters to ensure they are physically capable of performing the essential job tasks of structural fire fighting.

NFPA 1500 requires fire department members who engage in emergency operations to be annually evaluated and certified by the fire department as meeting the physical performance requirements identified in paragraph 8-2.1.[20] At the time of this report, the FD has implemented this recommendation on an annual basis.

Recommendation #3: Phase in a mandatory wellness/fitness program for fire fighters to reduce risk factors for cardiovascular disease and improve cardiovascular capacity.

Physical inactivity is the most prevalent modifiable risk factor for coronary artery disease in the United States. Additionally, physical inactivity, or lack of exercise, is associated with other risk factors: obesity and diabetes.[21] NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*, requires a wellness program that provides health promotion activities for preventing health problems and enhancing overall well-being.[20] NFPA 1583, *Standard on*

Health-Related Fitness Programs for Fire Fighters, provides the minimum requirements for a health-related fitness program.[22]

In 1997, the International Association of Fire Fighters (IAFF) and the International Association of Fire Chiefs (IAFC) published a comprehensive Fire Service Joint Labor Management *Wellness/Fitness Initiative* to improve fire fighter quality of life and maintain physical and mental capabilities of fire fighters. Ten fire departments across the United States joined this effort to pool information about their physical fitness programs and to create a practical fire service program. They produced a manual and a video detailing elements of such a program.[23] The FD should review these materials to identify applicable elements for the Department. Other large-city negotiated programs can also be reviewed as potential models. Wellness programs have been shown to be cost effective, typically by reducing the number of work-related injuries and lost work days.[24-26] A similar cost savings has been reported by the wellness program at the Phoenix Fire Department, where a 12-year commitment has resulted in a significant reduction in their disability pension costs.[27] At the time of this report, the FD has implemented this recommendation.

Recommendation #4: Conduct exercise stress tests (EST) for fire fighters with two or more risk factors for coronary artery disease (CAD).

NFPA 1582 and the IAFF/IAFC wellness/fitness initiative recommend EST for fire fighters with two or more CAD risk factors.[19,23] The AHA states EST may be indicated for individuals with two or more risk factors for CAD who are over 45 years of age.[28] The EST could be conducted by the fire fighter's personal physician or the City contract physician. If the fire fighter's personal physician conducts the test, the results must be communicated to the City physician, who should be responsible for decisions regarding medical clearance for fire fighting duties.

At the time of this report, the FD has implemented this recommendation on an annual basis.

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