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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 *Ocotber 2008*

Fire Fighter Trainee Suffers Heart Attack During Simulated Fire Suppression Exercise—North Carolina

SUMMARY

A 34-year old male volunteer Fire Fighter Trainee attended a 3 month fire fighter certification course at the Regional Fire Academy. On August 14, 2007, the Trainee participated in a simulated fire suppression exercise consisting of rotating fire attack positions and maneuvering a 1¾-inch charged hoseline for about 30 minutes. After the exercise, participants returned to the classroom. Upon entering the classroom, the Trainee leaned against the wall, complained of chest pain, and collapsed. 9-1-1 was called as vital signs were taken, revealing a blood pressure of 70 millimeters of mercury (mmHg) systolic and a heart rate of 170 beats per minute. Despite supportive measures in the field and en route to the hospital, the Trainee remained in a semi-conscious state, with low blood pressure, and a fast heart rate. Inside the hospital's Emergency Department, an electrocardiogram (EKG) showed the Trainee was suffering from a heart attack and a cardiac arrhythmia (atrial fibrillation with rapid ventricular response). He underwent emergent cardiac catheterization which revealed an acute thrombus completely occluding his left main coronary artery. A stent was placed, but the Trainee went into cardiogenic shock which required prolonged resuscitation measures that resulted in anoxic brain damage. Two days later, the Trainee was declared brain dead by a consulting neurologist. After consultation with the family, the Trainee was taken off life support systems and died. The autopsy report listed the cause of death as "Acute myocardial infarction with systemic multi-organ effects of severe hypotension." NIOSH investigators agree with these reports, and that the heart attack was probably triggered by the moderate to severe physical exertion associated with the Trainee's simulated fire suppression training.

The Fire Fighter Fatality Investigation and Prevention Program is conducted by the National Institute for Occupational Safety and Health (NIOSH). The purpose of the program is to determine factors that cause or contribute to fire fighter deaths suffered in the line of duty. Identification of causal and contributing factors enable researchers and safety specialists to develop strategies for preventing future similar incidents. The program does not seek to determine fault or place blame on fire departments or individual fire fighters. To request additional copies of this report (specify the case number shown in the shield above), other fatality investigation reports, or further information, visit the Program Web site at

www.cdc.gov/niosh/fire/

or call toll free

1–800–CDC–INFO (1–800–232–4636)

The NIOSH investigator offers the following recommendations to address general safety and health issues. Had these recommendations been in place, perhaps the Trainee's sudden cardiac death could have been prevented at this time.

- Provide mandatory pre-placement and annual medical evaluations to fire fighters consistent with National Fire Protection Association (NFPA) 1582, Standard on Comprehensive Occupational Medical Program for Fire Departments, to determine their medical ability to perform duties without presenting a significant risk to the safety and health of themselves or others.
- Ensure fire fighters are cleared for duty by a physician knowledgeable about the physical demands of firefighting, the personal protective equipment used by fire fighters, and the various components of NFPA 1582.
- Perform a candidate and an annual physical performance (physical ability) evaluation to ensure fire fighters are capable of performing the essential job tasks of structural firefighting.
- Phase-in a comprehensive wellness and fitness program for fire fighters to reduce risk factors for cardiovascular disease and improve cardiovascular capacity.
- Provide fire fighters with medical clearance to wear self-contained breathing apparatus (SCBA) as part of the Fire Department's medical evaluation program.

INTRODUCTION & METHODS

On August 14, 2007, a 34-year-old male Trainee lost consciousness shortly after fire suppression training at the Regional Fire Academy. Despite resuscitation efforts by the instructors, crew members, ambulance personnel, and Emergency Department and hospital personnel, the Trainee died. NIOSH was notified of this fatality on August 20, 2007, by the United States Fire Administration. On August 22, 2007, NIOSH contacted the affected Fire Department to gather additional information, and on January 16, 2008 to initiate the investigation. On January 28, 2008, a Safety and Occupational Health Specialist from the NIOSH Fire Fighter Fatality Investigation Team traveled to North Carolina to conduct an on-site investigation of the incident.

During the investigation, NIOSH personnel interviewed the following people:

Fire Chief
Fire Academy Coordinator
Crew members at the combination Fire Department
Trainee's parent

NIOSH personnel reviewed the following documents:

Fire Department policies and operating guidelines
Fire Department training records
Fire Department annual report for 2007
Emergency Medical Service (EMS)/ambulance incident report

Emergency department record
Hospital records
Death certificate
Autopsy record
Primary care provider medical records
Military medical records

RESULTS OF INVESTIGATION

Incident. On August 14, 2007, at about 0730 hours, the Trainee drove about an hour to attend Fire Fighter I and Fire Fighter II training at the Regional Fire Academy. He was on the last day of the 3-month training course. The Trainee arrived at about 0830 hours for the fire control exercise and class. The temperature was 84-degrees Fahrenheit with 43% relative humidity, giving a heat index of 83.8-degrees Fahrenheit [NOAA 2007].

The students began the day with a simulated fire suppression exercise consisting of rotating fire attack positions and maneuvering a 1¾-inch charged hoseline. The 30-minute exercise was performed with participants wearing full turnout gear (jacket, pants, boots, gloves, helmet) weighing approximately 25 pounds. After completing the exercise, the class removed their turnout gear and returned to the classroom for a 10-minute break.

As the Trainee removed his turnout gear, he leaned against the wall, and stated that he didn't feel well. The instructor was notified and entered the classroom along with a paramedic and an emergency medical technician. They found the Trainee complaining of severe pain in his chest, shortness of breath, being nauseated, and sweating heavily; seconds later, he collapsed. 9-1-1 was called (1007 hours) as oxygen was administered and vital signs were taken. The Trainee was found to have a blood pressure of 70 mmHg systolic (normal is 100-120), a heart rate between 120-180 beats per minute (normal is 60-100), and a respiratory rate of 28 breaths per minute (normal is 8-14). At about 1010 hours, the Trainee's heart rate dropped and he began to have agonal respirations. An automated external defibrillator was applied to the Trainee's chest, but no shocks were advised. The Trainee's pulse stopped and CPR was successfully administered by the class instructor and another paramedic for about 2 minutes when the Trainee regained a heart rhythm, pulse, and consciousness.

The ambulance arrived at 1021 hours. Paramedics found the Trainee conscious with a blood pressure of 78 mmHg systolic, a pulse rate of 180 beats per minute, and breathing 28 times per minute. He continued to report severe chest pain, shortness of breath, being nauseated, and heavy sweating. An intravenous (IV) line was placed, and a cardiac monitor revealed atrial fibrillation with a fast ventricular response. Cardizem® for the arrhythmia was given via IV with minimal change in the Trainee's condition. The ambulance departed the scene at 1040 hours for the local hospital's Emergency Department. En route, the Trainee had another cardiac arrest in the ambulance, but was revived within 2 minutes. He remained conscious throughout the remainder of the 8-minute transport.

The ambulance arrived at the hospital at 1050

hours. An EKG taken in the Emergency Department, showed the Trainee was suffering a heart attack in the posterior area of the left ventricle. Initial cardiac enzyme blood levels were normal, but became markedly elevated during his subsequent hospitalization. He was then prepared for emergency cardiac catheterization (1213 hours) and possible percutaneous angioplasty with stent placement.

An echocardiogram was performed in the catheterization lab which showed severely reduced left ventricle function (estimated ejection fraction of 25%) with no motion in the posterior and apex areas of the heart and markedly reduced motion in the anterior and lateral areas. The catheterization revealed a totally occluded left main coronary artery and a significantly occluded circumflex coronary artery. His right coronary artery was not occluded. An intra-aortic balloon pump was inserted to improve the Trainee's low blood pressure. Then a series of balloon inflations of the left main coronary artery and circumflex were conducted from 1256 – 1319 hours, followed by a stent placement. These procedures were successful at opening the blocked arteries and the Trainee was being prepared to leave the catheterization lab at 1332 hours.

Over the next 45 minutes, however, the Trainee's condition deteriorated and he went into cardiogenic shock at 1415 hours. CPR was begun and a repeat coronary angiogram showed the left main coronary artery stent had re-occluded. The Trainee was transferred to emergency open-heart surgery at 1455 hours. Inside the operating room, the Trainee's heart was not beating. A shock was delivered which resulted in the heart regaining a rhythm, but due to the extensive damage from the heart attack, this only resulted in a left ventricular ejection fraction of 5%. A left and right ventricular device was placed in the Trainee's heart, but the surgery was complicated by a bleeding problem which required re-opening the Trainee's chest on two separate occasions. Post surgery a neurologist was consulted regarding the extent of the Trainee's hypoxic brain damage due to his prolonged period of cardiogenic shock. Two electroencephalographs were performed on August 15 and 16. Both revealed no apparent electrical activity (brain death). After discussion with family members life support systems were removed and he died at 0025 hours on August 17, 2007.

Medical Findings. The death certificate, completed by the Medical Examiner on August 20, 2007 after the autopsy, listed the cause of death as "hypoxic brain injury (brain death)" due to "cardiogenic shock" due to "massive myocardial infarction" due to "coronary artery disease." Pertinent findings from the autopsy are listed in Table 1 which confirmed the presence of severe atherosclerotic coronary artery disease (CAD) and an acute heart attack.

The Trainee was 74" tall and weighed 252 pounds, giving him a body mass index (BMI) of 32.4. A BMI >30.0 kilograms per meters squared (kg/m2) is considered obese [CDC 2008]. The Trainee, however, was very muscular. The Trainee served in the military from 1990 to 1994. Other than a brief hospitaliza-

tion for infectious mononucleosis, his annual medical evaluations were normal. The Trainee's mother recalls, however, that during his mononucleosis illness her son had liver, spleen, and possibly heart damage.

In 2001 the Trainee was diagnosed with hypertension. The condition was not very well controlled due to compliance issues with his various antihypertensive medications. In 2006 the Trainee was diagnosed with high blood cholesterol. He was treated with limited success with a low cholesterol diet and cholesterol lowering medications.

In January 2007, the Trainee sought medical attention for episodes of palpations occurring daily over a 2-3 week period with atypical chest pain. Work-up by his primary care physician included an EKG which showed sinus tachycardia at a rate of 111 beats per minute and left ventricular hypertrophy by voltage criteria. 24-hour cardiac monitoring (Holter monitor) revealed rare premature atrial and ventricular contractions which did not correlate with his symptoms.

In April of 2007, the Trainee sought medical attention with a new primary care physician. In his health questionnaire, the Trainee checked yes to:

- "chest pain, tightness, pressure, or squeezing or burning in the chest during exertion or after meals"
- "palpitation or irregular heart beat"
- "difficulty breathing while active"
- "smoking 1/2 pack of cigarettes per day for the past 10 years"

At his follow-up examination in July (1 month prior to his heart attack) he reported poor exercise tolerance, fatigue, shortness of breath on exertion, and atypical chest pain on exertion. His physical examination showed no signs of congestive heart failure. Blood tests were normal except for an elevated cholesterol level (221 mg/dL – normal is 120-200) and a low blood count (hemoglobin of 10.4 g/dL – normal is 13.5-18.0). The physician recommended an imaging exercise stress test and a pulmonary function test. Unfortunately, the Trainee elected to postpone these tests due to his lack of health insurance.

DESCRIPTION OF THE FIRE DEPARTMENT

At the time of the NIOSH investigation, the combination Fire Department consisted of 29 volunteer uniformed personnel and served a population of 4,500 residents in a geographic area of 36 square miles. The Fire Department had one fire station.

In 2007, the Fire Department responded to 229 calls: 74 rescue/EMS assist/medical calls, 6 structure fires, 24 brush/grass/forest fires, 7 rubbish/trash/dump fires, 2 vehicle fires, 31 other fires, 14 hazardous condition calls, 11 motor vehicle accidents, 32 good intent/false alarm calls, 8 service calls, 6 calls cancelled en route, and 14 other calls.

Membership, Employment, and Training. The Fire Department requires all new volunteer fire fighter applicants to complete Fire Department orientation on personal protective equipment, hose, ladders, etc. and to complete the State Fire Academy, where the fire fighter candidate is trained to the Fire Fighter I and II levels. The Fire Department requires all new career fire fighter applicants to be pre-certified fire fighters who have completed the State Fire Academy. All fire fighters remain on probation for 12 months. The State voluntary minimum standard for fire fighter certification is NFPA 1001, Standard for Firefighter Professional Qualifications [NFPA 2008a]. The Trainee was a Fire Department member for 3 months and had just completed the Regional Fire Academy certification program for FFI and FFII, the day of his collapse.

Pre-placement and Annual Medical Evaluations. The Fire Department does not require a pre-placement or an annual medical evaluation for fire fighters. Medical clearance to wear SCBA is not required, but the Fire Department does perform annual SCBA facepiece fit testing.

The Regional Fire Academy did not require a medical evaluation prior to candidate training. However, a letter or telephone call from the candidate's Fire Chief was required stating the candidate was approved to attend training. The approval implied both physical ability and medical clearance.

Health and Wellness Programs. The Fire Department does not have a wellness/fitness program. However, fitness equipment (strength and aerobic) is available in the fire station. An annual fitness evaluation is not required. If a member is injured on duty, the fire fighter must be evaluated by the City-contracted Worker's Compensation physician, who makes the final determination regarding "return to work."

DISCUSSION

In the United States, CAD (atherosclerosis) is the most common risk factor for cardiac arrest and sudden cardiac death [Meyerburg and Castellanos 2008]. Risk factors for its development include age over 45, male gender, family history of CAD, diabetes, high blood pressure (hypertension), smoking, high blood cholesterol, and obesity/physical inactivity [American Heart Association (AHA) 2008a; Jackson et al. 2001]. The Trainee had five of these risk factors (male gender, smoking, hypertension, high blood cholesterol, and obesity).

The narrowing of the coronary arteries by atherosclerotic plaques occurs over many years, typically decades [Libby 2008]. However, the growth of these plaques probably occurs in a nonlinear, often abrupt fashion [Shah 1997]. Heart attacks typically occur with the sudden development of complete blockage (occlusion) in one or more coronary arteries that have not developed a collateral blood supply [Fuster et al. 1992]. This sudden blockage is primarily

due to blood clots (thromboses) forming on top of atherosclerotic plaques. The Trainee had an acute heart attack as demonstrated by his EKG, his cardiac enzymes, his cardiac catheterization, and his autopsy findings.

Epidemiologic studies have found that heavy physical exertion sometimes immediately precedes and triggers the onset of acute heart attacks [Willich et al. 1993; Mittleman et al. 1993; Siscovick et al. 1984; Tofler et al. 1992]. Heart attacks in fire fighters have been associated with alarm response, fire suppression, and heavy exertion during training (including physical fitness training) [Kales et al. 2003, Kales et al. 2007, NIOSH 2007]. The Trainee had maneuvered a charged 1¾-inch hoseline while rotating fire attack positions and wearing full turnout gear. This activity expended about 10 metabolic equivalents (METs), which is considered heavy physical activity [American Industrial Hygiene Association Journal 1971; Gledhill and Jamnik 1992]. Given the Trainee's underlying CAD, the physical stress of performing exertional training activities could have triggered a heart attack, causing his subsequent cardiac arrest and death.

Cardiomegaly/Biventricular Hypertrophy. On autopsy, the Trainee was noted to have both massive cardiomegaly and left and right ventricular hypertrophy. The cardiomegaly was probably due to edema associated with the myocardial infarction and open heart surgery, whereas his left ventricular hypertrophy was probably chronic due to longstanding hypertension and ischemic coronary artery disease. In addition to coronary artery disease, both cardiomegaly and LVH increase the risk of sudden cardiac death. The Trainee's left ventricular hypertrophy was first noted on his EKG in January of 2007. Unfortunately no further workup, such as an echocardiogram was recommended at that time.

Epstein-Barr Virus. The Trainee suffered from an episode of mononucleosis while he served in the military. The Epstein-Barr virus is the etiologic agent of acute infectious mononucleosis [Kawa 2000]. Infections occurring in infancy are typically asymptomatic, whereas about half of infections occurring in adolescence/early childhood have symptoms [CDC 2008]. Symptoms typically include a fever, sore throat, and swollen lymph nodes [Kawa 2000]. Less common manifestations can involve spleen, liver, and neurologic complications. Cardiac complications can occur but only during the acute setting such as inflammation of the surface of the heart muscle (pericarditis) or the heart muscle itself (myocarditis). Epstein-Barr virus infection is not known to cause CAD or a heart attack. The symptoms of infectious mononucleosis typically resolve in 1 or 2 months, although Epstein-Barr virus remains harmless in the person's body for the rest of their life [CDC 2008].

Occupational Medical Standards for Structural Fire Fighters. To reduce the risk of sudden cardiac arrest or other incapacitating medical conditions among fire fighters, the NFPA developed NFPA 1582, Standard on Comprehensive Occupational Medical Program for Fire Departments [NFPA 2007a]. This voluntary industry standard specifies minimum

medical requirements for candidates and current fire fighters.

Screening Tests for Cardiac Disease. In addition to screening for risk factors for CAD, NFPA 1582 recommends conducting diagnostic exercise stress tests on members with a) symptoms suggestive of CAD or b) asymptomatic fire fighters over the age of 45 with two or more CAD risk factors (hypercholesterolemia, hypertension, smoking, diabetes mellitus, or family history of premature CAD) [NFPA 2007a]. These recommendations are similar to those of the American College of Cardiology (ACC)/AHA [Gibbons et al. 2002]. The Trainee had chest pain consistent with angina and CAD, therefore an exercise stress test should have been performed. This was noted by his primary care provider in July 2007 who requested an imaging exercise stress test. Unfortunately, the primary care provider did not stress the urgency of this test. He allowed the Trainee to delay the tests for financial reasons. Had an imaging exercise stress test been performed, it is very likely his CAD would have been diagnosed and he would have been referred to a cardiologist for further evaluation and treatment, perhaps preventing his death at this time.

RECOMMENDATIONS

The NIOSH investigator offers the following recommendations to address general safety and health issues. Had these recommended programs been in place prior to 2007, perhaps the Trainee's sudden cardiac death could have been prevented at this time.

Recommendation #1: Provide mandatory pre-placement and annual medical evaluations to fire fighters consistent with National Fire Protection Association (NFPA) 1582, Standard on Comprehensive Occupational Medical Program for Fire Departments, to determine their medical ability to perform duties without presenting a significant risk to the safety and health of themselves or others.

Guidance regarding the content and frequency of these evaluations can be found in NFPA 1582 and in the International Association of Fire Fighters (IAFF)/International Association of Fire Chiefs (IAFC) Fire Service Joint Labor Management Wellness/Fitness Initiative [NFPA 2007a; IAFF, IAFC 2008]. However, the Fire Department is not legally required to follow this standard or this initiative. Applying this recommendation involves economic repercussions and may be particularly difficult for small, volunteer fire departments to implement. NFPA 1500, Standard on Fire Department Occupational Safety and Health Program, paragraphs A.10.6.4 and A.11.1.1 and the National Volunteer Fire Council (NVFC) Health and Wellness Guide address these issues [NFPA 2007b; USFA 2004].

To overcome the financial obstacle, the Fire Department could urge current members to get annual medical clearances from their private physicians. Another option is having the annual medical evaluations completed by paramedics and EMTs from the local Emergency Medical Service (vital signs, height, weight, visual acuity, and EKG). This information could then be provided to a community phy-

sician (perhaps volunteering his or her time), who could review the data and provide medical clearance (or further evaluation, if needed). The more extensive portions of the medical evaluations could be performed by a private physician at the fire fighter's expense (personal or through insurance), provided by a physician volunteer, or paid for by the Fire Department. Sharing the financial responsibility for these evaluations between fire fighters, the Fire Department, and physician volunteers may reduce the negative financial impact on recruiting and retaining needed fire fighters.

The State Fire Academy should implement a process to ensure a medical clearance form for each trainee is on file prior to allowing the trainee to participate in fire fighter training.

Recommendation #2: Ensure fire fighters are cleared for duty by a physician knowledgeable about the physical demands of firefighting, the personal protective equipment used by fire fighters, and the various components of NFPA 1582.

Guidance regarding medical evaluations and examinations for structural fire fighters can be found in NFPA 1582 [NFPA 2007a] and in the report of the IAFF/IAFC Fire Service Joint Labor Management Wellness/Fitness Initiative [IAFF, IAFC 2008]. According to these guidelines, the Fire Department should have an officially designated physician who is responsible for guiding, directing, and advising the members with regard to their health, fitness, and suitability for duty as required by NFPA 1500 [NFPA 2007b]. The physician should review job descriptions and essential job tasks required for all Fire Department positions and ranks, in order to understand the physiological and psychological demands of fire fighters and the environmental conditions under which they must perform, as well as the personal protective equipment they must wear during various types of emergency operations.

Recommendation #3: Perform a candidate and an annual physical performance (physical ability) evaluation to ensure fire fighters are capable of performing the essential job tasks of structural firefighting.

NFPA 1500 [NFPA 2007b], Standard on Fire Department Occupational Safety and Health Program, requires fire fighter candidates to be qualified as meeting the physical performance requirements established by the fire department prior to entering into a training program.

Specific guidelines to implement a candidate physical ability test can be found in the IAFF/IAFC Candidate Physical Ability Test [IAFF, IAFC 1999]. Fire department members who engage in emergency operations must be evaluated and certified annually by the fire department as meeting the physical performance requirements identified in paragraph 10.2.3 of NFPA 1500 [NFPA 2007b].

The Trainee in this case collapsed during physically exerting training to become a fire fighter. If a candidate physical ability test had been performed, perhaps the severity of the Trainee's medical condition would have been recognized by himself and others, and he

would have been restricted from becoming a fire fighter or limited to non-strenuous duties.

Recommendation #4: Phase-in a comprehensive wellness and fitness program for fire fighters to reduce risk factors for cardiovascular disease and improve cardiovascular capacity.

NFPA 1500 recommends that a fire department have a wellness program that provides health promotion activities for preventing health problems and enhancing overall well-being [NFPA 2007b]. Worksite health promotion programs have been shown to be cost effective by increasing productivity, reducing absenteeism, reducing the number of work-related injuries, and reducing the number of work-related lost work days [Maniscalco 1999; Stein 2000; Aldana 2001]. Fire service health promotion programs have been shown to reduce coronary artery disease risk factors and improve fitness levels, with mandatory programs showing the most benefit [Blevins 2006; Dempsey 2002; Womack 2005]. A recent study conducted by the Oregon Health and Science University reported a savings of over one million dollars for each of four large fire departments implementing the IAFF/IAFC wellness/fitness program compared to four large fire departments not implementing a program. These savings were primarily due to a reduction of occupational injury/illness claims with additional savings expected from reduced future non-occupational healthcare costs [Kuehl 2007].

Guidance for implementation and components of a comprehensive wellness/fitness program are found in NFPA 1583, Standard on Health-Related Fitness Programs for Fire Fighters [NFPA 2008b], in the IAFF/IAFC's Fire Service Joint Labor Management Wellness/Fitness Initiative [IAFF, IAFC 2008], and in the NVFC's Health and Wellness Guide [USFA 2004]. Given the Fire Department's structure, the NVFC program might be the most appropriate model. NIOSH recommends a formal, structured wellness/fitness program to ensure all members receive the benefits of a health promotion program.

Recommendation #5: Provide fire fighters with medical clearance to wear self-contained breathing apparatus (SCBA) as part of the Fire Department's medical evaluation program.

The Occupational Safety and Health Administration (OSHA)'s Revised Respiratory Protection Standard requires employers to provide medical evaluations and clearance for employees using respiratory protection [29 CFR[1] 1910.134]. These clearance evaluations are required for private industry employees and public employees in States operating OSHA-approved State plans. North Carolina operates an OSHA-approved State plan; therefore, public sector employers (including volunteer fire departments) are required to comply with OSHA standards.

[1]Code of Federal Regulations. See CFR in references.

Table 1

Autopsy Findings

- Coronary atherosclerotic disease, severe
  - — Severe (95%) focal narrowing of the left anterior descending coronary artery
  - — Moderate (50%) focal narrowing of the circumflex coronary artery
  - — Moderate (40%) focal narrowing of the right coronary artery
  - — No evidence of a thrombus (blood clot) (Note: intracoronary clots would have been removed/cleaned during the catheterization)
- Acute myocardial infarction, circumferential left ventricular distribution with extension into the right ventricle, massive
- Cardiomegaly (heart weighed 650 grams [g]) (normal weight is <400 g) [Siegel 1997]

(Note: the echocardiogram on August 14 showed only minimal cardiac enlargement, therefore this was probably due to edema associated with the myocardial infarction and open heart surgery)

- Congestive heart failure
  - — Biventricular dilatation
    - Left ventricle wall thickened (2.0 centimeters [cm]) normal at autopsy is 0.76-0.88 cm [Colucci and Braunwald 1997] normal by echocardiographic measurement is 0.6 to 1.0 cm [Connolly and Oh 2008]
    - Right ventricle wall thickened (1.0 cm) normal at autopsy is 0.3 cm - 0.5 cm [Klatt 2008]
  - — Systemic effects of severe hypotension/shock including hypoxic encephalopathy
- No evidence of a pulmonary embolus (blood clot in the lung arteries)

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