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Cardiometabolic health among United States firefighters by age

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ABSTRACT

Firefighting is strenuous work that results in considerable cardiovascular strain. Sudden cardiac events are the leading cause of duty-related death in the fire service. This cross-sectional study examined cardiometabolic measures and prevalence of risk factors in firefighters by age and sex and compare these data to the general population. Data obtained at medical exams (2015–2018) from 4279 male and 234 female career firefighters at four occupational health clinics in the United States were analyzed. Estimates for the general population were obtained using the 2015–16 National Health and Nutrition Examination Survey fasting subsample. Linear regression models stratified by sex with age modelled as a continuous variable were used to examine general trends. Point estimates across age groups (20–29, 30–39, 40–49, and 50–59 year olds) for cardiometabolic measures were reported. Among the total sample, 36% were obese and 25% had low HDL cholesterol. Females had significantly lower body mass index (BMI), LDL cholesterol, triglycerides and blood glucose than males. A significant quadratic relationship of age with BMI, total cholesterol, LDL cholesterol, and triglycerides was found in males with increasing values peaking between 45 and 50 years. Total cholesterol and LDL cholesterol increased with age among females. Blood glucose increased with age in both sexes. Firefighters had similar or better cardiometabolic health profiles than the US general population; however, both samples had a concerning prevalence of cardiometabolic risk factors among individuals $\geq$ 40 years of age. Health professionals and fire service members alike should consider prevention efforts among young firefighters and better treatment among older firefighters.

1. Introduction

Atherosclerotic cardiovascular disease (ASCVD) is the leading cause of death and disability in North America among civilians (Virani et al., 2020). The accumulation of lipid plaque in the arterial wall and associated inflammation are hallmark characteristics of ASCVD. The central role of altered metabolic parameters in cardiovascular disease has led to the concept of cardiometabolic disease. The Framingham study (Mahmood et al., 2014) and other large epidemiological research studies (Kannel, 1988; Huxley et al., 2002; Stamler and Neaton, 2008; Eckel et al., 2010) have established that cardiometabolic risk factors including obesity, blood lipids, blood glucose, and metabolic syndrome are important predictors of ASCVD and of sudden cardiac death. Metabolic syndrome is defined as a clustering of cardiometabolic risk factors that increases the risk of incident cardiovascular disease, sudden cardiac death, and diabetes (Eckel et al., 2010). Firefighters are an important occupational cohort who need to maintain their cardiometabolic health throughout their careers given the physiological strain of firefighting (Smith et al., 2014; Fahs et al., 2011; Fernhall et al., 2012; Smith et al., 2016; Smith et al., 2001) data showing that sudden cardiac events account for nearly 50% of duty-related deaths in this group (Fahy et al., 2019), and a high prevalence of obesity reported in the fire service (Poston et al., 2011; Soteriades et al., 2005; Byczek et al., 2004). Research documenting a substantial increase in risk of duty-related cardiac events among older firefighters emphasizes the need to examine cardiometabolic health by age in the fire service (Farioli et al., 2015; Geibe et al., 2008).

Studies with firefighters have reported large variability in the of prevalence of obesity, ranging from 19% to 51% (Poston et al., 2011; Soteriades et al., 2005; Donovan et al., 2009; Li et al., 2017; Davis et al.,

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2002; Clark et al., 2002; Choi et al., 2016; Kales et al., 1999; Smith et al., 2012). Importantly, obesity is associated with a fourfold increase in risk of duty-related coronary heart disease related death (Geibe et al., 2008). Studies examining lipid profiles in firefighters have also found divergent prevalence values, likely due in part to differences in the age of the sample, different cut-points for defining risk factors, and other characteristics of the sample population. A recent study on male firefighters working in California found a concerningly high prevalence of high cholesterol (33%), triglycerides (36%), and low HDL cholesterol (43.4%) (Choi et al., 2016). Metabolic syndrome, defined as a clustering of these and other risk factors, is increasing in the general population (Hirode and Wong, 2020), and studies have reported a prevalence of 10–28% among firefighters (Donovan et al., 2009; Li et al., 2017; Choi et al., 2017; Baur et al., 2012). Previous research assessing cardiometabolic health in the fire service has generally relied on a single fire department or relatively small sample sizes of male firefighters, and produced conflicting results. Currently, no studies with data from multiple locations across the United States have reported cardiometabolic risk factors by age and sex as compared to the general population. Comparisons of cardiometabolic health between those with prior military service and the general population have been conducted to provide insights on the health risks of prior military service (Janak et al., 2016). Given the cardiovascular strain of firefighting and the greatly increased risk of sudden cardiac events following firefighting activity compared to station duties, examining the cardiometabolic health of firefighters throughout their careers as compared to the general population can provide insights on whether further prevention efforts or treatment options are required and if they differ by age. Therefore, the objectives of this study were to: 1) compare cardiometabolic measures and prevalence of risk factors in male and female firefighters, 2) describe cardiometabolic health metrics and the prevalence of cardiometabolic risk factors among firefighters by age and sex, and 3) and compare measures and prevalence within each age group and sex to the general population.

2. Methods

2.1. Study population

Data from firefighter occupational medical exams performed between 2015 and 2018 from four geographically distinct occupational health clinics were used for this study. These clinics performed medical evaluations for career US fire departments in the Southwest, Mid-Atlantic, Southeast, and Mid-West. The fire departments all provided structural firefighting services, and depending upon location, may also respond to brush or wildland fires. All members of a fire department were required to receive annual medical evaluations. Data on LDL cholesterol, HDL cholesterol and triglycerides were not available from one department (n = 256) and medication usage was not available in one clinic (n = 366). Female firefighters from the Southeast and Southwest cohorts were not included in the analysis due to small sample sizes within age categories. The analytical sample was 4513 firefighters (males n = 4279; females n = 234). Each clinic de-identified the datasets prior to sharing the electronic data files with researchers from the First Responder Health and Safety Laboratory at Skidmore College. The study protocol was reviewed and approved by the Skidmore College Institutional Review Board. Data from the publicly available 2015–16 National Health and Nutrition Examination Surveys (NHANES) were used to generate estimates of the general population. The fasting subsample of the 2015–16 NHANES included 703 male and 782 female adults (20–59 years of age) (enters for Disease Control and Prevention: NHANES Related Documentation, 2016).

2.2. Data collection

The National Fire Protection Association's 1582 Standard on Comprehensive Occupational Medical Program for Fire Departments (Technical Committee on Fire Service Occupational Safety and Health, 2018) sets minimum standards for the medical clearance of firefighters. These guidelines were followed by health care professionals who provided annual medical evaluations for all incumbent firefighters within a fire department. Height and weight were recorded using a stadiometer and a standard physician's scale. Blood samples were obtained from firefighters in the fasted state and evaluated for standard blood chemistry and lipid profiles by a commercial laboratory.

Definitions. Cardiometabolic data for firefighters and the general population were grouped by age in decades (20–29, 30–39, 40–49, 50–59 years of age). Prevalence estimates for cardiometabolic risk factors were defined based on measured values using the current national standard cut-points: obesity as body mass index (BMI) $\geq$ 30 kg/m^2 (Arnett et al., 2019); high total cholesterol $\geq$ 240 mg/dL or taking lipid lowering medications (National Cholesterol Education Program Expert Panel, 2002), low HDL cholesterol $<$ 40 mg/dL for males and $<$ 50 mg/dL for females (Arnett et al., 2019), high triglycerides $\geq$ 200 mg/dL (Arnett et al., 2019), and high blood glucose $>$ 125 mg/dL or taking medication for blood glucose control (Centers for Disease Control and Prevention, 2015).

Estimates of metabolic syndrome were calculated using four of the five criteria in the National Cholesterol Education Program (NCEP) definition (National Cholesterol Education Program Expert Panel, 2002). NCEP bases a diagnosis of metabolic syndrome on meeting three out of five criteria: abdominal obesity (measured as waist circumference $>$ 102 cm for males, and $>$ 88 cm for females), systolic blood pressure $\geq$ 130 mmHg or diastolic blood pressure $\geq$ 80 mmHg or taking hypertensive medication, triglycerides $\geq$ 150 mg/dL, blood glucose $\geq$ 110 mg/dL or taking medications, and HDL cholesterol $<$ 40 mg/dL in males and $<$ 50 mg/dL in females (National Cholesterol Education Program Expert Panel, 2002). Firefighters in the current study were considered to have metabolic syndrome if they met three or more of the criteria for which data were available from the occupational medical records (elevated systolic or diastolic blood pressure, triglycerides, blood glucose, HDL-cholesterol). Waist circumference was not consistently measured across clinics and therefore was not included in the definition of metabolic syndrome. Because only four of the five criteria were available, our estimates would underestimate true prevalence of metabolic syndrome, but this approach allowed the investigation of changes across ages. In order to allow a reasonable comparison to the general population, we also calculated metabolic syndrome in the general population based on having three or more of the four criteria available in the firefighter dataset.

2.3. Statistical methods

Descriptive values are presented as mean $\pm$ standard deviation. Linear and logistic regression models were used to test for differences in cardiometabolic variables between males and females adjusting for age and geographical location. Mean cardiometabolic values and risk factor prevalence were estimated for each specified age group by sex using separate linear or logistic regression models; model outputs (e.g., predicted means and standard errors) were calculated as though there were equal number of observations in each of the geographical locations. When a geographic location did not contain any subjects with a risk factor, all age groups were combined and a logistic regression model was conducted with a categorical variable for age groups and a categorical variable for location. For continuous outcomes, trends analyses were conducted using linear regression models with age modeled as a continuous variable and included a categorical term for cohort/location. A step-down approach starting with age modelled as a quadratic function was applied given the relationship observed from the point estimates within each age group. Wald tests were conducted to determine if the quadratic relationship was significant. The margins command was used to estimate the predicted values for each age accounting for the

correlation between the coefficients for age and age squared, and the age in which the inflection point occurred was identified. Percentages of risk factors for each age group from the combined firefighter sample were also compared to the general population using the 2015–16 NHANES. NHANES uses a complex, multistage, probability sampling design which prevents making direct statistical comparisons by combining with other datasets (Centers for Disease Control and Prevention: Analytic Guidelines, 2018). To compare percentages with risk factors between the combined firefighter cohort and NHANES, 83.4% confidence intervals of the predicted values in each dataset were calculated where non-overlapping confidence intervals indicated a type 1 error of $P < 0.05$ with the assumptions that the variances were equal and estimates were independent (Knol et al., 2011). The level of significance for all analyses was considered at $P < 0.05$ and was two sided for all tests. All analyses were conducted using Stata 15.1 (StataCorp, College Station, TX, USA).

3. Results

The mean age of male and female firefighters was 42.4 ± 9.1 years and 40.5 ± 8.8 years, respectively, and the sample was predominantly white (86%) (Table 1).

Among the total sample of firefighters, 36 ± 1% were obese, 20 ± 1% had high cholesterol, 25 ± 1% had low HDL cholesterol, 12 ± 1% had high triglycerides, 4 ± 0.4% had high blood glucose, and 9 ± 1% had at least three out of the four available NCEP criteria for defining metabolic syndrome (Table 2).

Female firefighters had healthier cardiometabolic profiles than male firefighters with significantly lower levels of BMI, LDL cholesterol, triglycerides and blood glucose and a lower percentage with ≥ 3 criteria for metabolic syndrome.

For the analyses across age categories, a significant quadratic relationship was observed with BMI across age groups in male firefighters with the predicted peak at 49 years of age (Table 3).

Among female firefighters, a significant quadratic or linear relationship was not observed between age and BMI. Significant quadratic associations between total cholesterol, HDL cholesterol, and LDL cholesterol with age were also found for male firefighters with the predicted peaks at 47 years, 47 years and 45 years of age, respectively. Significant linear increases in total cholesterol and LDL cholesterol with age were found among female firefighters. Age was not significantly associated with HDL cholesterol in male or female firefighters. A significant quadratic relationship between triglycerides and age was found among males with the predicted peak at 50 years of age. For blood glucose, a significant quadratic relationship was observed in males with a continual non-linear increase with age and a significant linear increase with age among females. Proportions of firefighters with cardiometabolic risk factors across age groups were reported in Table 4.

Among males ages 20–29 years to 40–49 years, prevalence increased from 22% to 45% for obesity, from 19% to 30% for low HDL cholesterol, and from 5% to 16% for high triglycerides. Among males 20–29 years to 50–59 years, prevalence of high cholesterol increased from 3% to 40%. The prevalence of high blood glucose in males increased from 1% to 11% for those 20–29 to 50–59 years of age. Among females, from 20 to 29 to

Table 1
Descriptive statistics of a U.S firefighter cohort.

	Total	Males	Females
n	4513	4279	234
Age (yr)	42.4 ± 9.1	42.5 ± 9.1	40.5 ± 8.8
Height (m)	1.8 ± 0.1	1.8 ± 0.1	1.7 ± 0.1
Weight (kg)	95.1 ± 17.0	96.0 ± 16.6	77.8 ± 14.8
White (%)	86	86	85
African American/Black (%)	7	7	9
Hispanic (%)	4	4	3
Other (%)	3	3	3

Values are shown as mean ± SD or %.

Table 2
Measures of cardiometabolic health and prevalence of risk in male and female firefighters.

	Total	Male	Female	P value
Cardiometabolic Measures				
BMI (kg/m^2)	29.1 ± 0.1	29.2 ± 0.1	27.7 ± 0.3	<0.001
Total Cholesterol (mg/dL)	189.7 ± 0.7	189.9 ± 0.7	188.3 ± 2.3	0.53
LDL (mg/dL)	116.1 ± 0.7	116.5 ± 0.7	111.4 ± 1.9	<0.001
HDL (mg/dL)	48.7 ± 0.3	48.1 ± 0.3	59.4 ± 0.9	<0.001
Triglycerides (mg/dL)	121.7 ± 1.8	123.2 ± 1.8	87.2 ± 4.5	<0.001
Blood Glucose (mg/dL)	95.8 ± 0.3	96.2 ± 0.3	88.7 ± 0.8	<0.001
Prevalence of risk factors				
Obesity (%)	36 ± 1	37 ± 1	25 ± 3	<0.001
High Cholesterol (%)	20 ± 1	21 ± 1	6 ± 2	<0.001
Low HDL (%)	25 ± 1	25 ± 1	24 ± 3	0.081
High Triglycerides (%)	12 ± 1	12 ± 1	2 ± 1	<0.001
High Blood Glucose (%)	4 ± 0.4	5 ± 0.4	3 ± 1	0.67
NCEP Metabolic Syndrome Criteria[a]				
Meets ≥ 3 criteria (%)	9 ± 1	10 ± 1	5 ± 1	0.013

Values are shown as mean ± standard error or % ± standard error.
Linear and logistic regression models were conducted to compare cardiometabolic variables between male and female firefighters adjusting for age and location.

[a] The National Cholesterol Education Program defines metabolic syndrome as having ≥ 3 of the following cardiometabolic measures: increased waist circumference, elevated blood pressure, elevated blood glucose, low HDL cholesterol, and elevated triglycerides. Waist circumference was not consistently available from the occupational medical exams, only 4 of the 5 measures were considered in the definition of metabolic syndrome in the firefighter and general population samples; therefore, the reported percentages meeting ≥ 3 criteria underestimates the prevalence of metabolic syndrome.

Table 3
Cardiometabolic measures among firefighters by age group and sex.

	20–29 yr	30–39 yr	40–49 yr	50–59 yr	P value
BMI (kg/m^2)					
Male Firefighters	27.7 ± 0.2	28.6 ± 0.2	30.2 ± 0.2	29.9 ± 0.2	<0.001[a]
Female Firefighters	26.7 ± 1.0	27.3 ± 0.5	28.2 ± 0.5	27.4 ± 0.9	0.46
Total Cholesterol (mg/dL)					
Male Firefighters	173.5 ± 1.7	185.8 ± 1.2	198.8 ± 1.4	192.9 ± 1.8	<0.001[a]
Female Firefighters	178.9 ± 5.7	180.2 ± 3.7	193.0 ± 3.6	200.0 ± 6.5	<0.001[b]
LDL (mg/dL)					
Male Firefighters	104.9 ± 1.7	114.3 ± 1.2	124.0 ± 1.3	116.4 ± 1.7	<0.001[a]
Female Firefighters	102.4 ± 4.3	105.2 ± 3.0	115.8 ± 3.2	119.9 ± 5.0	<0.001[b]
HDL (mg/dL)					
Male Firefighters	49.8 ± 0.7	48.8 ± 0.4	46.8 ± 0.5	48.3 ± 0.6	0.044[a]
Female Firefighters	59.6 ± 2.1	58.8 ± 1.7	60.0 ± 1.5	59.8 ± 2.8	0.69
Triglycerides (mg/dL)					
Male Firefighters	93.6 ± 3.6	112.1 ± 2.9	140.6 ± 3.6	133.7 ± 4.0	<0.001[a]
Female Firefighters	84.2 ± 6.6	81.3 ± 5.2	88.7 ± 9.3	95.3 ± 12.6	0.36
Blood Glucose (mg/dL)					
Male Firefighters	90.5 ± 0.5	92.8 ± 0.4	98.0 ± 0.6	101.6 ± 1.0	<0.001[a]
Female Firefighters	84.2 ± 1.3	87.8 ± 1.8	89.2 ± 1.1	94.4 ± 2.0	<0.001[b]

Values are shown as mean ± standard error.
[a] Indicates a significant quadratic relationship with age.
[b] Indicates a significant linear relationship with age.

Table 4
Prevalence of risk factors among firefighters by age group and sex.

	20–29 yr	30–39 yr	40–49 yr	50–59 yr
Obesity (%)				
Male Firefighters	22 ± 2	30 ± 2	45 ± 2	44 ± 2
General Population	32 ± 7	40 ± 6	48 ± 4	43 ± 4
Female Firefighters	22 ± 8	23 ± 5*	24 ± 6*	22 ± 8*
General Population	33 ± 4	42 ± 3	41 ± 4	46 ± 6
High Cholesterol (%)				
Male Firefighters	3 ± 1*	9 ± 1*	23 ± 1	40 ± 2
General Population	9 ± 2	21 ± 4	24 ± 5	48 ± 5
Female Firefighters	2 ± 2	6 ± 3	7 ± 3*	6 ± 4*
General Population	6 ± 2	5 ± 2	19 ± 3	37 ± 4
Low HDL (%)				
Male Firefighters	19 ± 3	21 ± 2*	30 ± 2	26 ± 2
General Population	22 ± 4	31 ± 4	25 ± 4	31 ± 4
Female Firefighters	15 ± 6	24 ± 5	25 ± 5	33 ± 8
General Population	28 ± 3	31 ± 6	34 ± 5	28 ± 4
High Triglycerides (%)				
Male Firefighters	5 ± 1	8 ± 1*	16 ± 1	14 ± 2
General Population	5 ± 2	14 ± 2	19 ± 3	22 ± 4
Female Firefighters	2 ± 2	1 ± 1*	2 ± 2	6 ± 4
General Population	3 ± 3	7 ± 3	7 ± 3	15 ± 4
High Blood Glucose (%)				
Male Firefighters	1 ± 0.4*	1 ± 0.3*	4 ± 1*	11 ± 1*
General Population	4 ± 2	6 ± 1	10 ± 3	26 ± 4
Female Firefighters	2 ± 2	1 ± 1	2 ± 1*	7 ± 5
General Population	1 ± 1	4 ± 1	11 ± 3	18 ± 4
NCEP Metabolic Syndrome[a](meets ≥ 3 criteria) (%)				
Male Firefighters	4 ± 1	4 ± 1*	12 ± 1	16 ± 2*
General Population	4 ± 2	12 ± 3	14 ± 3	27 ± 4
Female Firefighters	0 ± NA	5 ± 3	4 ± 2*	14 ± 6
General Population	2 ± 1	6 ± 2	16 ± 3	19 ± 4

Values shown as prevalence ± SE
*Indicates a significant difference of $P < 0.05$ between firefighters and the general population
[a] The National Cholesterol Education Program defines metabolic syndrome as having ≥ 3 of the following cardiometabolic measures: increased waist circumference, elevated blood pressure, elevated blood glucose, low HDL cholesterol, and elevated triglycerides. Waist circumference was not consistently available from the occupational medical exams, only 4 of the 5 measures were considered in the definition of metabolic syndrome in the firefighter and general population samples; therefore, the reported percentages meeting ≥ 3 criteria underestimates the prevalence of metabolic syndrome.

50–59 years of age the prevalence of high cholesterol increased from 2% to 6% and the prevalence of high blood glucose increased from 2% to 7%.

Compared to the general population, both male and female firefighters tended to have consistently lower prevalence of cardiometabolic risk factors, although statistical significance was found inconsistently across the age groups and outcomes (Table 4). Specifically, male firefighters had lower prevalence ($P < 0.05$) of high cholesterol than the general population among < 40 year olds and lower prevalence of high blood glucose across all age groups. Female firefighters had lower prevalence ($P < 0.05$) of obesity than the general population among those > 30 years of age and lower prevalence of high cholesterol among those > 40 years of age.

4. Discussion

This study is the first to present the prevalence of cardiometabolic risk factors in a large diverse sample of male and female career firefighters by age and compare risk factor prevalence to the general population. The results of this study showed that metabolic health metrics in firefighters worsened with increasing age, generally peaking in male firefighters aged 45–50 years and continually increasing with age among female firefighters. High prevalence of cardiometabolic risk factors and metabolic syndrome was observed in older firefighters. Female firefighters had significantly lower prevalence of obesity, high cholesterol, high triglycerides, and metabolic syndrome than male firefighters. Compared to the general population, firefighters had similar or lower prevalence of cardiometabolic risk factors. Notably, male firefighters had significantly lower prevalence of high blood glucose than the general population across all age groups, and female firefighters had significantly lower obesity prevalence than the general population except among those 20–29 years of age. These findings suggest that firefighters have similar or better cardiometabolic health profiles than the US general population; however, both populations had a high prevalence of cardiometabolic risk factors which continued to worsen with increasing age. These results reinforce the importance of monitoring firefighter health and wellness throughout their careers as cardiometabolic health tends to decline with age while the responsibilities of active duty firefighters remain the same. Further, these results highlight the need for lifestyle interventions early in firefighters' careers to mitigate worsening cardiometabolic risk profiles and increased risk of cardiovascular disease and diabetes mellitus. Health care providers are in a unique position to encourage firefighters to embrace lifestyle changes to mitigate against the development of cardiometabolic risk factors and to aggressively address risk factors.

Obesity in the fire service has been a concern for many years, though the prevalence reported in literature varies greatly based on different ages, geographic location, and year studied. Obesity prevalence in cohorts from Colorado (Donovan et al., 2009; Li et al., 2017) and California (Choi et al., 2016) range from 19% to 23%. While these are the lowest reported values, the results indicate that nearly a quarter of firefighters were obese. More frequently, studies have reported an obesity prevalence in firefighters between 30% and 39% (Clark et al., 2002; Poston et al., 2011; Soteriades et al., 2005; Byczek et al., 2004), which is similar to the current study's overall obesity prevalence of 36%. Notably, previous studies included younger firefighters, with an average age 4 to 9 years lower than firefighters in the current study. Several studies investigating firefighters (Byczek et al., 2004; Davis et al., 2002; Kales et al., 1999; Smith et al., 2020) and the general population (Virani et al., 2020; Mahmood et al., 2014) have shown that obesity increases with advancing age. The current analyses showed a significant quadratic relationship between BMI and age, with BMI peaking at 49 years of age. It is unclear if this is due to increased self-awareness of cardiovascular health or more guidance from health providers for this age group. Interestingly, female firefighters in our study had an obesity prevalence of 25%, which is nearly twice what has been reported by others (Li et al., 2017; Smith et al., 2020), but is still approximately 12% lower than male firefighters in the current study. Only two known studies have presented obesity prevalence in female firefighters, with findings of 10% (Smith et al., 2020) and 11% (Li et al., 2017). Our study's higher female obesity prevalence might be attributed to the much larger and geographically diverse sample size as well as the older age of female firefighters in the current study compared to previous studies (2.5 to 3 years older).

Firefighters in the current study had lower prevalence of high cholesterol, high triglycerides, and low HDL cholesterol than what has been reported in the literature. Previous studies have reported a high cholesterol prevalence in firefighters ranging from 24%−70% (Byczek et al., 2004; Choi et al., 2016; Soteriades et al., 2002); which is higher than our high cholesterol prevalence of 21% in male firefighters and 6% in female firefighters. Similarly, the prevalence of high triglycerides in the current study (12% in males) was between 8 and 24% lower than previous reports in male firefighters (Poston et al., 2011; Byczek et al., 2004; Li et al., 2017; Choi et al., 2016; Soteriades et al., 2002). The prevalence of low HDL cholesterol in the current study (25%) closely matched what was reported in a cohort of Colorado firefighters (26%) (Donovan et al., 2009) but was approximately 10% lower than a cohort of Massachusetts firefighters assigned to hazardous materials teams (35%) (Soteriades et al., 2002) and less than half the prevalence found in firefighters from the Missouri Valley (60%) (Poston et al., 2011). Healthier lipid levels in this firefighter cohort may reflect overall health improvements since the time of previous research publications. Our analyses found significant quadratic associations with age and total

cholesterol (peak at 47 years), LDL cholesterol (peak at 45 years), triglycerides (peak at 50 years) and HDL cholesterol (nadir at 47 years). These findings are consistent with better lipid management or lifestyle interventions aimed at decreasing cardiometabolic risk after age 45. It is also possible that less healthy firefighters between the ages of 50–59 are more likely to retire which could contribute to the observed plateau of cardiometabolic health between the ages of 40–49 and 50–59 year olds.

High blood glucose levels are indicative of insulin resistance and are associated with increased risk for cardiovascular disease and cardiac events. A study comparing the health status of active firefighters to those who died of traumatic injury and those who died of cardiac events found that diabetes was associated with a six-fold increased risk of experiencing a duty-related fatal cardiac event (Kales et al., 2003). We found that blood glucose levels increased with age in both males and females with a mean blood glucose level of 101.6 mg/dL and prevalence of high blood glucose of 11% for male firefighters 50–59 years. Other studies have reported a prevalence of diabetes $\leq$ 2% in firefighters (Poston et al., 2011; Li et al., 2017; Choi et al., 2016; Smith et al., 2012). Our results are similar to previous reports of diabetes in male firefighters, but no known studies have examined blood glucose levels or diabetes in female firefighters with the exception of Li et al. (2017), who found 1 out of 76 female firefighters were hyperglycemic (Li et al., 2017). Elevated blood glucose is an important component of the metabolic syndrome, is a risk factor for diabetes, and increases the risk of ASCVD. While we did not find a high prevalence of elevated blood glucose compared to previous studies in the fire service, we did show increases with older age, suggesting a concerning trend for firefighters as they advance in their careers.

Metabolic syndrome is strongly associated with diabetes mellitus and adverse cardiovascular events (Eckel et al., 2010). The average prevalence of metabolic syndrome in the current study, identified as having $\geq$ 3 of the four risk criteria available, was 9% overall (10% in male firefighters and 5% in female firefighters). Previous research has reported widely divergent prevalence of metabolic syndrome with values between 10 and 15% for male firefighters in some studies (Donovan et al., 2009; Li et al., 2017; Choi et al., 2017), and values surpassing 25% in others (Baur et al., 2012; Carey et al., 2011). Although, the studies reporting values above 25% did not adhere precisely to the NCEP guidelines for assessing obesity (Baur et al., 2012) or rely on laboratory assessed lipid profiles (Carey et al., 2011). Far fewer studies have investigated metabolic syndrome in female firefighters but Li et al. reported a prevalence of 5% (Li et al., 2017). Metabolic syndrome in the current study was primarily driven by high blood pressure, which is consistent with our previous study reporting a high prevalence of hypertension in the fire service (Smith et al., 2020). Given the importance of metabolic syndrome as a precursor to diabetes mellitus, and as risk factor for cardiovascular disease and sudden death, we recommend that occupational health clinics collect all measures needed to assess metabolic syndrome (including waist circumference), and that the risks associated with metabolic syndrome be discussed with firefighters.

In the current study, firefighters had similar or lower prevalence of risk factors than the general population. Li et al reported that both male and female Colorado firefighters had lower prevalence of high triglycerides and high blood glucose and a higher prevalence of low HDL cholesterol than the general population (Li et al., 2017), which partially agrees with our findings. Studies which have examined obesity in female firefighters also found lower prevalence than the general population, though they did not compare the populations by age group (Li et al., 2017; Gendron et al., 2018; Jahnke et al., 2012). Several studies have suggested that the prevalence of obesity in male firefighters exceeded that of the US general population (Poston et al., 2011; Byczek et al., 2004; Kales et al., 1999); however, our results challenge those findings as we found no significant difference in obesity prevalence compared to the general population. While our findings suggest that firefighters have similar or better cardiometabolic health than the general population, the high prevalance of risk factors (e.g., over 40% of firefighters over 40 years of age were obese) remains a concern given that firefighters are called upon to exert maximal effort under stressful conditions that could trigger a cardiac event in individuals underlying cardiovascular disease. Thus, firefighters may be at a greater risk for triggering a cardiovascular event because of work related stress than a sedentary worker with similar disease states. Furthermore, traditional cardiometabolic risk factors do not account for all the risk associated with a cardiovascular disease. Inflammation, oxidative stress, autonomic balance, and hemostatic balance may be other factors that influence disease progression and risk of sudden cardiac events.

The findings of the current study extend the literature by reporting cardiometabolic measures, prevalence of cardiometabolic risk factors, and prevalence of metabolic syndrome by decade of life in male and female firefighters and by comparing risk factor prevalence to the general population by age. We found that firefighters had similar or better cardiometabolic profiles than the general population. Strengths of this study include a lack of selection bias, since all firefighters in participating departments were required to complete the annual occupational medical exams. We also report on the largest sample of male and female firefighters known to date, representing several regions of the US. Despite these strengths, this cohort was not representative of the national fire service at large. Our results do not represent volunteer firefighters. The cross-sectional nature of the study design cannot exclude the potential bias of less healthy firefighters retiring in their 50′s, which could partially explain the quadratic relationship of age and cardiometabolic health. Further, the reported prevalence of metabolic syndrome is an underestimation of true prevalence because waist circumference was not available to be included in our analysis.

While it is encouraging that firefighters do not have higher prevalence of cardiometabolic risk factors than the general population, the overall high prevalence of various risk factors is concerning especially given the unique occupational demands of firefighting and the risk of duty-related cardiovascular events in the fire servicey (Fahy et al., 2019). Health care professionals and fire service members alike should consider a comprehensive program that addresses screening, prevention, counseling and treatment of cardiometabolic risk factors. Further, these efforts should be instituted early in the careers of firefighters given that aging is associated with worsening cardiometabolic health and many firefighters remain operationally active throughout their careers.

CRediT authorship contribution statement

Steven M. Moffatt: Conceptualization, Investigation. **Donald F. Stewart:** Investigation. **Kepra Jack:** Investigation. **Monique D. Dudar:** Writing - original draft. **Emilie D. Bode:** Writing - original draft, Methodology. **Kevin C. Mathias:** Conceptualization, Methodology, Data curation, Formal analysis. **Denise L. Smith:** Conceptualization, Methodology, Writing - original draft, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Arnett, D.K., Blumenthal, R.S., Albert, M.A., Buroker, A.B., Goldberger, Z.D., Hahn, E.J., Himmelfarb, C.D., Khera, A., Lloyd-Jones, D., McEvoy, J.W., Michos, E.D., Miedema, M.D., Muñoz, D., Smith, S.C., Virani, S.S., Williams, K.A., Yeboah, J., Ziaeian, B., 2019. 2019 ACC/AHA Guideline on the Primary Prevention of Cardiovascular Disease: A Report of the American College of Cardiology/American

Heart Association Task Force on Clinical Practice Guidelines. Circulation 140 (11). https://doi.org/10.1161/CIR.0000000000000678.
Baur, D.M., Christophi, C.A., Kales, S.N., 2012. Metabolic syndrome is inversely related to cardiorespiratory fitness in male career firefighters. J. Strength Cond. Res. 26, 2331–2337.
Byczek, L., Walton, S.M., Conrad, K.M., Reichelt, P.A., Samo, D.G., 2004. Cardiovascular risks in firefighters: implications for occupational health nurse practice. AAOHN 52 (2), 66–76.
Carey, M., Al-Zaiti, S., Liao, L., et al., 2011. A low-glycemic nutritional fitness program to reverse metabolic syndrome in professional firefighters: results of a pilot dtudy. J. Cardiovasc. Nurs. 26, 298–304. https://doi.org/10.1097/JCN.0b013e31820344d7.
Centers for Disease Control and Prevention. National Health and Nutrition Examination Survey: NHANES 2015-16 Questionnaires, Datasets, and Related Documentation. Available at: https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/default.aspx?BeginYear=2015.
Centers for Disease Control and Prevention. National Health and Nutrition Examination Survey: Analytic Guidelines, 2011-2014 and 2015-2016. pp. 1–40. Available at https://wwwn.cdc.gov/nchs/data/nhanes/analyticguidelines/11-16-analytic-guidelines.pdf.
Choi, BongKyoo, Steiss, D., Garcia-Rivas, J., Kojaku, S., Schnall, P., Dobson, M., Baker, D., 2016. Comparison of body mass index with waist circumference and skinfold-based percent body fat in firefighters: adiposity classification and associations with cardiovascular disease risk factors. Int. Arch. Occup. Environ. Health 89 (3), 435–448. https://doi.org/10.1007/s00420-015-1082-6.
Choi, BongKyoo, Ko, SangBaek, Kojaku, S., 2017. Resting heart rate, heart rate reserve, and metabolic syndrome in professional firefighters: A cross-sectional study. Am. J. Ind. Med. 60 (10), 900–910. https://doi.org/10.1002/ajim.v60.1010.1002/ajim.22752.
Clark, S., Rene, A., Theurer, W.M., Marshall, M., 2002. Association of body mass index and health status in firefighters. J. Occup. Environ. Med. 44 (10), 940–946. https://doi.org/10.1097/00043764-200210000-00013.
Davis, S.C., Jankovitz, K.Z., Rein, S., 2002. Physical fitness and cardiac risk factors of professional firefighters across the career span. Res. Q. Exerc. Sport 73 (3), 363–370. https://doi.org/10.1080/02701367.2002.10609033.
Donovan, R., Nelson, T., Peel, J., Lipsey, T., Voyles, W., Israel, R.G., 2009. Cardiorespiratory fitness and the metabolic syndrome in firefighters. Occup. Med. Lond. 59 (7), 487–492. https://doi.org/10.1093/occmed/kqp095.
Eckel, R.H., Alberti, KGMM, Grundy, S.M., Zimmet, P.Z., 2010. The metabolic syndrome. Lancet 375 (9710), 181–183. https://doi.org/10.1016/S0140-6736(09)61794-3.
Fahs, C.A., Huimin Yan, Ranadive, S., Rossow, L.M., Agiovlasitis, S., Echols, G., Smith, D., Horn, G.P., Rowland, T., Lane, A., Fernhall, B.o., 2011. Acute effects of firefighting on arterial stiffness and blood flow. Vasc. Med. 16 (2), 113–118. https://doi.org/10.1177/1358863X11404940.
Fahy, R.F., Petrillo, J.T., Moliz, J.L. 2019. Firefighter Fatalities in the United States. Available at: https://www.nfpa.org/News-and-Research/Data-research-and-tools/Emergency-Responders/Firefighter-fatalities-in-the-United-States.
Farioli, A., Christophi, C.A., Quarta, C.C., Kales, S.N., 2015. Incidence of sudden cardiac death in a young active population. J Am Heart Assoc 4 (6). https://doi.org/10.1161/JAHA.115.001818.
Fernhall, B.o., Fahs, C.A., Horn, G., Rowland, T., Smith, D., 2012. Acute effects of firefighting on cardiac performance. Eur. J. Appl. Physiol. 112 (2), 735–741. https://doi.org/10.1007/s00421-011-2033-x.
Geibe, J.R., Holder, J., Peeples, L., Kinney, A.M., Burress, J.W., Kales, S.N., 2008. Predictors of on-duty coronary events in male firefighters in the United States. Am. J. Cardiol. 101 (5), 585–589.
Gendron, P., Lajoie, C., Laurencelle, L., et al., 2018. Cardiovascular disease risk in female firefighters. Occup Med (Lond) 68, 412–414. https://doi.org/10.1093/occmed/kqy074.
Hirode, G., Wong, R.J., 2020. Trends in the prevalence of metabolic syndrome in the United States, 2011–2016. JAMA 323, 2526–2528. https://doi.org/10.1001/jama.2020.4501.
Huxley, R., Lewington, S., Clarke, R., 2002. Cholesterol, coronary heart disease and stroke: A review of published evidence from observational studies and randomized controlled trials. Semin. Vasc. Med 2, 315–324. https://doi.org/10.1055/s-2002-35402.
Jahnke, S.A., Poston, WS.C., Haddock, C.K., Jitnarin, N., Hyder, M.L., Horvath, C., 2012. The health of women in the US fire service. BMC Womens Health 12 (1). https://doi.org/10.1186/1472-6874-12-39.
Janak, J.C., Pérez, A., Alamgir, H., et al. 2016. U.S. military service and the prevalence of metabolic syndrome: Findings from a cross-sectional analysis of the cooper center longitudinal study, 1979–2013, Prev. Med. 95:52–58. https://dx.doi.org/10.1016/j.ypmed.2016.11.017.
Kales, S.N., Polyhronopoulos, G.N., Aldrich, J.M., Leitao, E.O., Christiani, D.C., 1999. Correlates of body mass index in hazardous materials firefighters. J. Occup. Environ. Med. 41 (7), 589–595. https://doi.org/10.1097/00043764-199907000-00007.
Kales, S.N., Soteriades, E.S., Christoudias, S.G., Christiani, D.C., 2003. Firefighters and on-duty deaths from coronary heart disease: a case control study. Environ. Health 2 (1). https://doi.org/10.1186/1476-069X-2-14.
Kannel, W.B., 1988. Cholesterol and risk of coronary heart disease and mortality in men. Clin. Chem 34, B53.
Knol, M.J., Pestman, W.R., Grobbee, D.E., 2011. The (mis)use of overlap of confidence intervals to assess effect modification. Eur. J. Epidemiol. 26 (4), 253–254. https://doi.org/10.1007/s10654-011-9563-8.
Li, K., Lipsey, T., Leach, H.J., et al., 2017. Cardiac health and fitness of Colorado male/female firefighters. Occup. Med. Lond. 67, 268–273. https://doi.org/10.1093/occmed/kqx033.
Mahmood, S.S., Levy, D., Vasan, R.S., Wang, T.J., 2014. The Framingham Heart Study and the epidemiology of cardiovascular disease: A historical perspective. Lancet 383 (9921), 999–1008. https://doi.org/10.1016/S0140-6736(13)61752-3.
Mayo Clinic. Diagnosis and Treatment of Diabetes. Available at: https://www.mayoclinic.org/diseases-conditions/diabetes/diagnosis-treatment/drc-20371451.
National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III). Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) Final Report, Circulation 2002;106:3143–421.
Poston, W.S., Haddock, C., Jahnke, S., et al. 2011. The prevalence of overweight, obesity, and substandard fitness in a population-based firefighter cohort, J. Occup. Environ. Med. 53:266–273 https://dx.doi.otg/10.1097/JOM.0b013e31820af362.
Smith, D.L., DeBlois, J.P., Kales, S.N., et al., 2016. Cardiovascular strain of firefighting and the risk of sudden cardiac events. Exerc. Sport Sci. Rev. 44, 90–97.
Smith, D.L., Horn, G.P., Petruzzello, S.J., et al. 2014. Clotting and fibrinolytic changes after firefighting activities, Med. Sci. Sports Exerc. 46:448–454, https://dx.doi.org/10.1249/MSS.0b013e3182a76dd2.
Smith, D.L., Manning, T.S., Petruzzello, S.J., 2001. Effect of strenuous live-fire drills on cardiovascular and psychological responses of recruit firefighters. Ergonomics 44 (3), 244–254. https://doi.org/10.1080/00140130121115.
Smith, D.L., Fehling, P.C., Frisch, A., Haller, J.M., Winke, M., Dailey, M.W., 2012. The prevalence of cardiovascular disease risk factors and obesity in firefighters. J. Obes. 2012, 1–9. https://doi.org/10.1155/2012/908267.
Smith, D.L., Graham, E., Stewart, D., et al., 2020. Cardiovascular disease risk factor changes over 5 years among male and female US firefighters. J. Occup. Environ. Med. 62, 398–402. https://doi.org/10.1097/JOM.0000000000001846.
Soteriades, E.S., Kales, S.N., Liarokapis, D., Christoudias, S.G., Tucker, S.A., Christiani, D.C., 2002. Lipid profile of firefighters over time: Opportunities for prevention. J. Occup. Environ. Med. 44 (9), 840–846.
Soteriades, E.S., Hauser, R., Kawachi, I., et al., 2005. Obesity and cardiovascular disease risk factors in firefighters: A prospective cohort study. Obes Res 13, 1756–1763.
Stamler, J., Neaton, J.D., 2008. The Multiple Risk Factor Intervention Trial (MRFIT)–importance then and now. JAMA 300, 1343–1345. https://doi.org/10.1001/jama.300.11.1343.
Technical Committee on Fire Service Occupational Safety and Health. NFPA 1582: Standard on Comprehensive Occupational Medical Program for Fire Departments. Quincy, USA: National Fire Protection Association, 2018.
Virani, S.S., Alonso, A., Benjamin, E.J., Bittencourt, M.S., Callaway, C.W., Carson, A.P., Chamberlain, A.M., Chang, A.R., Cheng, S., Delling, F.N., Djousse, L., Elkind, M.S.V., Ferguson, J.F., Fornage, M., Khan, S.S., Kissela, B.M., Knutson, K.L., Kwan, T.W., Lackland, D.T., Lewis, T.T., Lichtman, J.H., Longenecker, C.T., Loop, M.S., Lutsey, P.L., Martin, S.S., Matsushita, K., Moran, A.E., Mussolino, M.E., Perak, A.M., Rosamond, W.D., Roth, G.A., Sampson, U.K.A., Satou, G.M., Schroeder, E.B., Shah, S.H., Shay, C.M., Spartano, N.L., Stokes, A., Tirschwell, D.L., VanWagner, L.B., Tsao, C.W., 2020. Heart disease and stroke statistics—2020 update: A report from the American Heart association. Circulation 141 (9). https://doi.org/10.1161/CIR.0000000000000757.