

Firefighters and COVID-19: An Occupational Health Perspective

Keywords: cardiovascular disease, COVID-19, firefighters, obesity, Sars-CoV-2

D iagnoses of coronavirus disease 2019 (COVID-19) from the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) were first reported in December 2019. Since its emergence from the Chinese province of Wuhan, the World Health Organization (WHO) has announced 162 million confirmed cases of the SARS-CoV-2 infection worldwide, and reported roughly 3.3 million deaths as of May 16, 2021.¹ Stratified by country, the United States leads with nearly 33 million confirmed COVID-19 cases, followed by India, Brazil, France, Turkey, and Russia.²

Structural firefighters perform essential public safety work and have continued that work despite the challenges of COVID-19. Career firefighters typically have long work schedules (24 or 48 hours on duty followed by multiple days off) and eat and sleep at the station as part of a team/shift. Firefighters respond to multiple hazards which include fires and rescues. In many localities, firefighters are dual trained as emergency medical service (EMS) personnel and provide emergency medical care. Because of their close living quarters and contact with the public, including rendering patient care and transporting patients, it is likely that firefighters are at an increased risk of infection with SARS-CoV-2. The fire service is aware of the risk of infection and has quickly adopted the increased use of personal protective equipment (PPE) and modified policies and procedures aimed at reducing the risk to firefighters.^{3,4} However, very little attention has been paid to occupational risks that may increase the severity of COVID-19 or to the potential long-term consequences of COVID-19 that may pose specific concerns for firefighters. The purpose of this review is to 1) outline the pathogenesis of COVID-19, 2) explore clinical and mechanistic links between COVID-19 and cardiovascular disease, 3) review known risk factors for COVID-19 complications and their prevalence among firefighters, and 4) consider steps that can be taken to better understand the long-term consequences of COVID-19 in the fire service. The review is limited to occupational factors for structural firefighters and does not cover wildland firefighters, although we acknowledge that COVID-19 may also present special concerns for wildland firefighters.

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Clinical significance: Occupational exposures to smoke, particulate matter, and other pulmonary and cardiovascular irritants may make firefighters vulnerable to increased inflammation and to cardiovascular and pulmonary conditions associated with COVID-19 complications. The long-term implications of COVID-19 are particularly concerning for firefighters who must perform strenuous work and have multiple occupational exposures.

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PATHOGENESIS OF COVID-19

The SARS-CoV-2 virus enters the body predominantly via the lungs, and often results in pronounced respiratory symptoms. Thus COVID-19 was initially described as a respiratory disease. Indeed, respiratory failure from acute respiratory distress syndrome has been shown to be leading cause of COVID-19 induced mortality.⁵ A study by Guan et al⁶ reported that the majority of COVID-19 related consequences feature pneumonia and acute respiratory distress, which is consistent with other analyses suggesting that about 40% of COVID-19 patients develop acute respiratory distress syndrome, and 20% of these syndromes are severe.⁷ Wang et al⁸ showed that 61% of the individuals that required intensive care due to COVID-19 developed acute respiratory distress syndrome. COVID-19 not only lead to respiratory symptoms, but also underlying respiratory conditions increase the likelihood of experiencing severe symptoms. Meta-analyses revealed that the odds of severe COVID-19 infection were 5.69 times higher if individuals who have a history of chronic obstructive pulmonary disease.⁹

The virus requires the cooperation of two key proteins, TMPRSS2, and angiotensinogen converting enzyme 2 (ACE2) to infiltrate the body via the lung pneumocytes. TMPRSS2 is a key cellular regulator of coronavirus spike protein (S protein), with the S1 domain of the S protein responsible for receptor binding and the S2 domain controlling membrane fusion. Thus, coronavirus requires the binding of the S1 region to a cell surface receptor followed by the S2 subunit mediated fusion of the viral and cellular membranes in order to enter its host.¹⁰ This process requires S protein priming, or cleavage, by host proteases at the S1 and S2 domains of the virus. This process has been described as a principle step for the cellular entry of SARS-CoV-2.¹¹

Following S protein cleavage, Sars-CoV-2 binds to and enters lung cells via the enzyme ACE2, which is highly expressed in alveolar type 2 cells.¹² Dissimilar to the original SARS-CoV, it has been suggested that SARS-CoV-2 may have a higher affinity to ACE2 positive cells in the upper respiratory tract, exacerbating its potent and detrimental effects.¹¹ ACE2 is a membranous protein and importantly, an inactivator of angiotensin II (AngII). The binding of SARS-CoV-2 to ACE2 in lung cells promotes the endocytosis of the ACE2-SARS-CoV-2 complex, resulting in a reduction of membrane ACE2 abundance and an increase in serum AngII.¹² Thus, SARS-CoV-2's affinity for ACE2 could explain its downstream effects on vascular parameters, including alterations in systolic and diastolic blood pressures, as elevated plasma AngII can increase blood pressure via aldosterone-mediated vasoconstriction and sodium and water retention on the kidneys.¹³ Furthermore, increased plasma AngII is associated with increased risks of myocardial infarction and left ventricular hypertrophy.¹³ In addition, SARS-CoV-2 promotes inflammation via the AT1R.¹² The AngII-AT1R axis activates pro-inflammatory transcription factors NF- κ B and STAT3, upregulating pro-inflammatory cytokines such as TNF α and IL-6 family cytokines,^{12,14} possibly leading to vascular inflammation and disease. Furthermore, recent studies suggest that the Sars-CoV-2 protein ORF3a encourages an aggressive inflammatory response via NF- κ B activation, chemokine secretion, Golgi fragmentation, ER stress, and cell death.¹⁵ ORF3a can also inhibit type I interferon (type I IFN) signaling, downregulate major histocompatibility complex

(MHC) class I expression, and reduce CD8⁺ cytotoxic T cell activity. Specifically, Siu et al¹⁵ demonstrated that ORF3a encourages the binding of TRAF3 to cytoplasmic portions of TNF receptors, promoting ubiquitination, and processing of p105 to p50. P50 is generated by TRAF3 ubiquitin-ligase ubiquitination of p150 and 26S proteasome-mediated removal of p105C terminal sequences. P50 then binds to RelA, RelB, or C-Rel subunits to produce functional NF- κ B, a transcription factor essential for pro-IL-1 β expression. The prevalence of pro-IL-1 β transcripts is a requirement for NLRP3 inflammasome activation. Therefore, ORF3a-mediated p105 processing into p50 can help activate the NLRP3 inflammasome and lead to a robust inflammatory response.¹⁵ Siu et al further demonstrated ORF3a's ability to induce ASC polyubiquitination via a TRAF3 ubiquitin-ligase.¹⁵ ASC is the adapter complex of the NLRP3 inflammasome, and polyubiquitination of ASC provides a nondegradative signal necessary for ASC activation, caspase-1 activation, and mature IL-1 β protein formation.¹⁵ Ultimately, the studies mentioned above illustrate how COVID-19 can target the cardiovascular system through its mode of entry and lead to vascular inflammation and dysfunction via upregulation of pro-inflammatory signaling.

COVID-19 AND CARDIOVASCULAR DISEASE

Although SARS-CoV-2 was first described as a respiratory disease, cardiac tissue and blood vessels express ACE2 receptors and appear to be particularly prone to COVID-19 infection.¹⁴ The heart, an ACE2 expressing tissue, was studied during the Toronto SARS outbreak (SARS-CoV), and investigators found evidence of SARS-CoV RNA in 35% of autopsied hearts.¹⁶ COVID-19 acts in a similar manner to the previous SARS-CoV, indicating that individuals with cardiovascular disease (CVD) are more prone to severe complications of SARS-CoV-2 compared to healthy individuals.

Initial research on CVD-induced complications of COVID-19 was conducted in China. Wang et al investigated the association between biomarkers of CVD and the exacerbation of COVID-19 in hospitalized patients and found that cardiac injury, defined as either elevated high-sensitivity cardiac troponin I (hs-cTnI) or ECG/echocardiographic abnormalities, was present in 7.2% of the patients.^{8,17,19} The study also found that 22% of COVID-19 patients in ICU had biomarkers of cardiac injury.^{8,17} Zhou et al reported that hs-cTnI levels were at or greater than the 99th percentile upper reference limit in 46% of non-survivors, compared to only 1% of survivors who had levels this high.^{17,18} Thus, it has become apparent that COVID-19 can have severe cardiovascular consequences. Ultimately, it is also becoming clear that the presence of CVD, or CVD risk factors, can increase the likelihood of severe complications of COVID-19.

The observational study by Zhou et al described above, also reported that 8% of patients (13% of non-survivors) had been diagnosed with CVD and 38% (48% of non-survivors) had been diagnosed with hypertension.^{17,18} Furthermore, Wang et al found that comorbidity of COVID-19 and CVD was prevalent in 15% (25% requiring ICU care) of patients analyzed, and Guan et al reported that 2.5% (9% among those with intubation or death) of COVID-19 patients also suffered from coronary artery disease.^{10,11,14} Chen et al demonstrated that in a cohort of 99 COVID-19 infected individuals at the Wuhan Jinyintan Hospital, 40% had some manifestation of cardiovascular or cerebrovascular disease.¹⁹ Other researchers have also reported on the higher prevalence of hypertension among COVID-19 patients; one study that although reports 15% of COVID patients had hypertension, 36% of those who needed intubation or suffered death had hypertension. Another study reported 31% of patients with COVID-19 had hypertension; however, 58% of patients requiring ICU care had hypertension.^{6,8} These findings demonstrate a clinical link between COVID-19 and CVD.

EFFECT OF COVID-19 ON CARDIOVASCULAR SYSTEM

Following the COVID-19 outbreak, researchers have begun to investigate the mechanisms associating COVID-19 and CVD. Emerging evidence strongly suggests the SARS-CoV-2 infection decreases myocardial functioning. Previous research has demonstrated that SARS-CoV, resembling both the structure and function of SARS-CoV-2, perturbs myocardial functioning.²⁰ Recent research analyzing the cardiac manifestations of the SARS-CoV-2 infection found that the most common cardiac abnormality (39% of patients at baseline) was right ventricular dilation and dysfunction, followed by left ventricular diastolic and systolic dysfunction (16% and 10% of patients at baseline, respectively).²¹ In this study, 20% of these patients had clinical deterioration, with 60% of them having right ventricle deterioration and 25% having left ventricle systolic and diastolic deterioration.²⁰ Thus, it appears that COVID-19, similar to other severe hypoxic respiratory illnesses, impairs cardiac function mostly by a right ventricular pressure overload state.

Myocardial injury involves a pronounced escalation in pro-inflammatory cytokine secretions, which is commonly seen in COVID-19 patients. Specifically, research has found that patients suffering from COVID-19 had an upregulation of the pro-inflammatory cytokines IL1B, IFN γ , IP10, and MCP1. Individuals in ICU admission for COVID-19 had higher concentrations of the cytokines GCSF, IP10, MCP1, MIP1A, and TNF α than those not in ICU.²² An increase in these molecules due to COVID-19 severity can lead to an activation and dysregulation of T helper cells.²² Imbalances in (type 1 and type 2) T helper cells can lead to respiratory dysfunction, hypoxemia, and myocardial injury.²⁰ Interestingly, Huang et al noticed that type 2 T-helper cell cytokines (IL4 and IL10), that suppress inflammation, were upregulated during infection of SARS-CoV-2.²⁰ A study of competitive athletes recovering from COVID-19 found that 15% (4/26) had cardiovascular magnetic resonance findings suggestive of myocarditis despite only 2 of the 4 participants with findings suggestive of myocarditis having had COVID-19 symptoms.²³

Acute thrombotic events are another major complication in individuals fighting the SARS-CoV-2 infection. Blood hypercoagulability has been shown to be common among hospitalized COVID-19 patients.²⁴ Elevated D-Dimer levels, associated with thrombus formation and breakdown, are also reported in COVID-19 patients, worsening over the course of the disease.²⁴ A review by Terpos et al elegantly describes how thrombus degradation products including PT and aPT are consistently upregulated in individuals requiring ICU admission.²⁴ COVID-19 has also been shown to induce acute pulmonary embolisms in certain individuals,²⁴⁻²⁷ and one study found that 30% of COVID-19 patients had acute pulmonary embolus, measured by a CT coronary angiogram.²⁸ This rate of pulmonary embolus is higher than what is usually seen in critically ill patients without COVID-19 (1.3%).²⁸ Ultimately, COVID-19 patients are at higher risk for thromboembolic events, leading to adverse cardiovascular health risks.

The endothelium plays key roles in regulating blood flow, maintaining hemostatic balance, and in immune response. Emerging evidence suggests that a vascular disease process contributes to COVID-19 pathogenesis.²⁹ Several studies have begun to elucidate the role of endothelial dysfunction with COVID-19. Epithelial dysfunction, specifically pulmonary endothelial damage, is a common manifestation observed in patients infected with SARS Cov-2 virus and other coronaviruses.²⁶ Endothelium damage due to COVID-19 is thought to occur by multiple mechanisms, including: a dysregulated immune response, enhanced vascular permeability, and exacerbated presence of pulmonary edemas.^{26,30} Varga et al³¹ demonstrated endothelial cell dysfunction in vital organs of individuals after becoming infected with COVID-19. These authors presented convincing evidence to indicate that the SARS CoV-2 virus has direct effects on endothelial cells, possibly due to the fact

that ACE2 is also widely expressed on endothelial cells in multiple organs.¹⁴ Thus, it appears that recruitment of immune cells and pro-inflammatory cytokines due to ubiquitous expression of ACE2 can result in extensive endothelial dysfunction and cellular apoptosis.

THE EFFECTS OF OBESITY ON CARDIOVASCULAR HEALTH AND COVID-19

Obesity has been recognized as an important predictor of CVD risk and adverse cardiorespiratory outcomes. Genetic and clinical experiments have found that that obesity is causally related to many disease states including hypertension, diabetes mellitus type 2, coronary heart disease, stroke, atrial fibrillation, renal disease, and heart failure.³² Others have reported that around 75% of hypertension can be attributed to obesity.³³ It is clear that this obesity-induced hypertension leads to renal dysfunction due to an increased sympathetic nervous state and upregulated renin-angiotensin system.³³ Obesity has effects on the infection and exacerbation of the SARS-CoV-2 infection. Sattar et al propose that obesity and ectopic fat deposition might reduce both optimal cardiorespiratory and immune response mechanisms, two major factors that can lead to severe manifestations of COVID-19.³² Several studies have reported on an association between obesity and COVID-19. Hamer et al reported a two-fold risk ratio of being infected with COVID-19 for obese individuals compared to normal weight individuals.³⁴ These risk ratios were adjusted for age, sex, and mutually for each lifestyle, and physical inactivity. Furthermore, obesity was identified as the risk factor that contributed greatly to the prediction of COVID-19 infection risk. Finally, Hamer et al calculated a Population Attributable Fraction (PAF), which corresponds to the prevalence of risk factors in a population and the strength of its association with an outcome (COVID-19).³⁴ The PAF used adjusted effect estimates on lifestyle factors (smoking, physical inactivity, overweight, and obesity) and COVID-19 and found that the total PAF for the three unhealthy lifestyle factors was 51.4%.³⁴ Specifically, overweight and obesity had a PAF of 29.5%, smoking had a PAF of 13.3%, and physical inactivity had a PAF of 8.6%. Overall, it has become quite clear through both mechanistic and clinical research that there is a powerful effect of obesity on COVID-19 infection and severity.

POTENTIAL RELATIONSHIPS BETWEEN FIREFIGHTERS AND COVID-19

As discussed through this paper, there is a strong relationship between both pulmonary disease, CVD and COVID-19. While initial research has focused on risk factors that place individuals at increased risk for COVID-19 complications, this section details ways that occupational exposures and cardiovascular risk factors that are known to be prevalent among firefighters, might make firefighters an occupational group that is at high risk of developing COVID-19 complications and for whom the long-term effects of

COVID-19 infection might be particularly problematic. As summarized in Tables 1 and 2 and discussed in the following section, there are multiple factors that are known to exacerbate the rate of infection or severity of infection with SARS-CoV-2 and that are occupationally associated with firefighting.

Pulmonary Disease

Results from our recent study indicate that decrements in the respiratory function of career firefighters (age: 38.1 ± 7.7 years) was two-to-four-times greater than the estimated decrease expected in the general population.³⁵ Earlier reports agree with our findings and also show that the loss of pulmonary function in firefighters is associated with the frequency of fire exposure,³⁶ of particular concern since modern fires are producing more potent byproducts of combustion than previous decades.³⁷⁻⁴³ Based on their occupational exposures, firefighters appear to be at an increased risk of decreased pulmonary function. There is less evidence that firefighting leads to increased pulmonary disease, but this is a plausible argument. Certainly, pulmonary disease is associated with increased risk for developing a severe COVID-19 infection.

Pulmonary Disease Risk Factors: Smoke and Particulate Matter Exposure

Combating the acute and long-term effects of smoke and particulate matter exposure is a pertinent issue in the fire service. Reports have stated that heavy smoke and particulate matter exposure can acutely reduce firefighters forced expiratory volume in 1 second (FEV₁) by 5%, yet lung function often returns back baseline.⁴⁴⁻⁴⁶ Furthermore, Musk et al⁴⁴ demonstrated an average FEV₁ decrease of 0.05 L in firefighters following a week of smoke exposure, with 30% of the cohort having a FEV₁ decrease in excess of 0.1 L. Other studies have shown that overhaul, the stage in which firefighters search for and extinguish possible sources of reignition, can cause decreases in FEV₁ and forced vital capacity (FVC) as well as increases in serum Clara cell protein (CC16), and serum SP-A.⁴⁷

Longitudinal studies investigating the effects of long-term smoke and particulate matter exposure on firefighter cardiopulmonary health have been conducted, yet the results are inconclusive. A 6-year follow-up study conducted on firefighters from the Boston fire department showed that longitudinal changes in the FEV₁ and FVC were not associated with any index of firefighting exposure in active firefighters,⁴⁸ and that the protective respiratory equipment used by the fire service appeared to be combating the detrimental effects of enhanced smoke and particulate matter exposure. In addition, a review of 22 studies from 1974 to 2016 concluded that the influence of smoke and particulate exposure on firefighter health is unclear and limited by methods of measurement, and that non-routinely exposed firefighters suffer accelerated declines in pulmonary function.⁴⁹ However, a seminal study by Peters et al³⁶ found

TABLE 1. Association Between Medical Conditions of COVID-19 and Firefighting

Medical Conditions	COVID-19 Research	Fire Service Research
1. Pulmonary disease	<ul style="list-style-type: none"> Significantly associated with a severe COVID-19 infection (OR 5.69, 95% CI: 2.49–13.00)⁹ 30% of studied COVID-19 patients developed acute respiratory distress syndrome,²⁸ 61% of studied COVID-19 patients developed acute respiratory distress syndrome,^{7,8,28} with approximately 20% of these cases being severe⁸ 	<ul style="list-style-type: none"> Decrements in respiratory function were two-to-four-times greater in firefighters than general population³⁵ Pulmonary function is associated with frequency of fire exposure³⁶ Those who transitioned to less active assignments might not be protected from pulmonary disease⁸⁸
2. Cardiovascular disease	<ul style="list-style-type: none"> 15–40% of patients had some manifestation of cardiovascular or cerebrovascular disease^{7,8,19} 	<ul style="list-style-type: none"> Firefighters with other comorbidities demonstrated unfavorable CVD and cardiorespiratory fitness profiles⁷⁰

COVID-19, coronavirus disease 2019; CVD, cardiovascular disease.

TABLE 2. Association Between Risk Factors of COVID-19 and Firefighting

Risk Factors	COVID-19 Research	Fire Service Research
1. Age	<ul style="list-style-type: none"> • Significant association of older age (≥ 65 years) and risk of COVID-19 mortality • Ranging from an OR of 3.76 (95% CI: 1.15–17.39; $P = 0.023$) to 4.59 (95% CI: 2.61–8.04; $P < 0.001$)^{57,58} 	<ul style="list-style-type: none"> • 9% of the entire US firefighting cohort is 60 years of age or older⁵⁵
2. Sex	<ul style="list-style-type: none"> • Males have made up as much as 60.3–70% of patients hospitalized with the SARS-CoV-2 infection • Prostatic diseases are associated with elevations in COVID-19 induced cardiac injury (OR 1.505, 95% CI; $P = 0.046$)⁶⁰ • In males, each standard deviation increase in free androgen escalates risk of severe COVID-19 manifestations (OR 1.22, 95% CI: 1.03–1.45; $P = 0.024$)⁶⁰ 	<ul style="list-style-type: none"> • 96% of the US fire service is comprised of men, and more than half of US metropolitan departments have no women firefighters^{55,62}
3. Hypertension	<ul style="list-style-type: none"> • 56.6% of New York City area COVID-19 patients had hypertension⁵⁹ • Significant associate of COVID-19 mortality (pooled OR 2.70, 95% CI: 1.40–5.24; $P = 0.003$)⁵⁷ 	<ul style="list-style-type: none"> • Up to 30% of the entire fire service have hypertension^{63,72} • 46% of males and 29% of females firefighters had blood pressure measurements within the range of stage 1 or 2 hypertension⁶⁴ • 58% of career firefighters and 47% of volunteer firefighters have prehypertension⁶³
4. Obesity	<ul style="list-style-type: none"> • Has been ranked as the number one contribution of COVID-19 infection³⁴ • Younger, obese individuals are at greater risk for severe COVID-19 complications⁶⁵ 	<ul style="list-style-type: none"> • 72% of firefighters ($n = 50$) were classified as either overweight or obese⁸⁹ • Rates of overweight and obese firefighters may exceed the US prevalence⁷⁰
5. Cardiovascular physiology/pathology	<ul style="list-style-type: none"> • Cardiac troponin is significantly associated with COVID-19 mortality risk (OR 4.077, 95% CI: 1.166–14.253; $P < 0.001$)⁵⁸ • Apparent cardiac injury in 7.2% of all patients, and in 22% of ICU patients^{8,17} • 39% of patients had right ventricular dilation and dysfunction, 16% had left ventricular diastolic dysfunction, 10% had systolic dysfunction²¹ 	<ul style="list-style-type: none"> • Acute bouts of firefighting: decreases arterial compliance⁷³ can induce ventricular arrhythmias and markers of myocardial ischemia,⁷⁴ increases arterial stiffness,⁷⁶ and enhances blood coagulability⁷⁶
6. Smoke and particulate matter exposure	<ul style="list-style-type: none"> • Particulate matter exposure increased ACE2 and TMPRSS2 proteins in murine alveolar type 2 cells and macrophages⁵³ 	<ul style="list-style-type: none"> • Decrements in FVC were more than twice the expected rate in firefighters³⁶ • FVC decrements were related to frequency of fire exposure, but not to age, smoking habits, or ethnicity³⁶ • Firefighters who never wore a mask during fire extinguishing experienced a 1.7 times greater rate of FEV₁ decline compared to mask wearers⁵⁰

COVID-19, coronavirus disease 2019; FVC, forced vital capacity.

that the average decrements in firefighter FVC were more than twice the expected rate and was significantly related to frequency of fire exposure, but not to age, smoking habits, or ethnicity. Tepper et al⁵⁰ further showed that active firefighters experienced a 2.5× greater decline in FEV₁ compared to those who had retired or resigned. Moreover, firefighters who never wore a mask during fire extinguishing experienced a 1.7 times greater rate of FEV₁ decline compared to mask wearers.⁵⁰ Other studies have similarly shown that noncompliance with respiratory protection use accelerated FEV₁ decline in firefighters.⁵¹ Additionally, Aldrich et al⁵² showed that after 13 years of follow-up, there was a 10% decrease in the average FEV₁ of firefighters who responded to the World Trade Center Disaster. Thus, there is considerable but not conclusive evidence that exposure to smoke and particulate matter can both acutely and longitudinally perturb pulmonary function in firefighters, especially before widespread use of respiratory protective equipment in the fire service. As discussed, reduced pulmonary function is a robust correlate to COVID-19 infection and severe COVID-19 manifestation. Recent evidence also demonstrated that exposure to particulate matter can increase both ACE2 and TMPRSS2 proteins in murine alveolar type 2 cells and macrophages.⁵³ Consequently, particulate matter exposure due to

firefighting might have a direct effect on COVID-19 infection, but further research is necessary.

Cardiovascular Disease Risk Factors: Age

Firefighter cardiovascular health status is determined largely by the prevalence of cardiovascular risk factors which can include age, sex, hypertension, and obesity.⁵⁴ Data from 2018 shows that 9% of US firefighters are 60 years of age or older.⁵⁵ Although a relatively small number, this sub-cohort of the fire service might have a more pronounced risk of COVID-19 infection than the general population. A recent observational study reported that age is one of the leading risk factors for infection and death due to COVID-19.⁵⁶ Other studies have confirmed this finding, reporting that older individuals (≥ 65 years) have anywhere from 3.7 to 4.5 times higher risk of COVID-19 mortality.^{57,58}

Cardiovascular Disease Risk Factors: Sex

Evidence suggests that males are more susceptible to a COVID-19 infection than females, with one study observing data from the New York City area concluding that males made up 60.3% of the patients hospitalized with the SARS-CoV-2 infection.^{56,59} A study in China found that males made up 70% of the patients on

ventilators in the ICU.^{6,60} Moreover, males were more predominant in deceased COVID-19 patients than in recovered patients.⁵⁶

The discrepancy in male and female COVID-19 infection is thought to be due to differing levels of androgens between males and females. Specifically, TMRSS2 expression has been shown to be regulated by testosterone, and testosterone increases androgen receptor activity which is considered a requirement for the transcription of TMRSS2.⁶¹ Ghazizadeh et al⁶⁰ reported that prostatic diseases, disorders related to androgen imbalance, increased the odds of having abnormal troponin T levels (COVID-19 induced cardiac injury) by 50.5%. Utilizing the UK Biobank (UKBB), Ghazizadeh et al⁶⁰ also found that free androgen index significantly associated with COVID-19 susceptibility and severity in males, but not in females. Additionally, among males who were tested for COVID-19, each standard deviation increase in free androgen index increased the odds of a positive COVID-19 test, as well as severe COVID-19 infection, by 22%.⁶⁰

The fire service is predominately male. Jahnke et al⁶² reported that 3.7% to 5.1% of the US fire service is comprised of women, and more than half of US metropolitan departments have no women firefighters. Other data indicates that 4% of all career firefighters and 11% of all volunteer firefighters are female.⁵⁵ Nevertheless, an occupational group so dominated by men is most likely to be severely affected by the SARS-CoV-2, as higher androgen levels are ubiquitously found in men.

Cardiovascular Disease Risk Factors: Hypertension

Hypertension is a risk factor of COVID-19 and CVD that is known to have a high prevalence within the US fire service. Hypertension is frequently reported to be one of the most common comorbidities related to COVID-19 infection. In fact, Richardson et al found that hypertension was present in 56.6% of 5700 hospitalized COVID-19 patients within the New York City area.⁵⁹ A retrospective analysis extends these findings, concluding that chronic hypertension, along with other cardiovascular comorbidities, were more frequent among deceased patients than survivors (48% vs 14%, respectively).⁵⁶ Meta-analysis data also suggests that hypertension is significantly associated with COVID-19 mortality, and that individuals classified as hypertensive have 2.7 higher odds of dying from COVID-19 than a non-hypertensive individual.⁵⁷

Research indicates that approximately 20% to 30% of the entire fire service have hypertension.⁶³ Our recent study found that 46% of male firefighters and 29% of females had blood pressure measurements within the range of stage 1 or 2 hypertension.⁶⁴

Cardiovascular Disease Risk Factors: Obesity

As discussed earlier, obesity has been found to significantly increase the relative risk of a COVID-19 infection. Unfortunately, there is a high prevalence of obesity in the US fire service. Studies have shown that obesity was present in 41.7% of COVID-19 hospitalized individuals.⁵⁹ Interestingly, work by Kass et al demonstrates a significant inverse correlation between age and body mass index (BMI).⁶⁵ Thus, younger cohorts with pronounced obesity are at an increased risk of being infected with SARS-CoV-2. This emerging viewpoint is worrisome for the US fire service, as obesity is already a major CVD risk factor found in firefighters.

Obesity has also been found to significantly increase the risk of firefighter on-duty coronary heart disease fatality and links the mechanisms of firefighting-induced vascular alterations to sudden cardiac death.^{54,66} Data suggests that firefighters with high BMIs have impaired vascular function and are at a greater risk for CVD.⁶⁷⁻⁷⁰ Using a large sample of 947 male and 76 female subjects, a study by Poston et al examined the prevalence of cardiovascular risk factors in Colorado firefighters.⁷⁰ The results suggest that obese firefighters demonstrated unfavorable CVD and cardiorespiratory fitness profiles. Furthermore, obese firefighters in

both career and volunteer departments tended to have substandard cardiovascular health profiles, with an emphasis on elevated systolic and diastolic blood pressure and low HDL cholesterol levels.⁷⁰ Recent studies suggest that within different decades of life, the number of prevalent CVD risk factors in firefighters increased in each increasing BMI category.⁷¹

Acute Changes in Cardiovascular Physiology

Research has begun to elucidate the intimate relationship between COVID-19 and decrements in cardiovascular physiology. Acute cardiac injury and heart failure have been shown to be common in COVID-19, patients irrespective of a past diagnosis of CVD.⁵⁶ Furthermore, analyses by Du et al⁵⁸ reveal that cardiac troponin is significantly associated with COVID-19 mortality risk (OR 4.077, 95% CI 1.166 to 14.253; $P < 0.001$) while also demonstrating that cardiac troponin ≥ 0.05 ng mL⁻¹ is a predictor of COVID-19 mortality in a sex, age, and comorbid illness-matched case-control study.

Firefighting results in substantial cardiovascular strain.^{54,72} Research findings also demonstrate that firefighting activities can acutely promote cardiac fatigue and decreases in arterial compliance,⁷³ induce post-firefighting ventricular arrhythmias and markers indicating myocardial ischemia,⁷⁴ increase arterial stiffness,⁷⁵ and enhance blood coagulability that is not reduced immediately after firefighting⁷⁶ or by post-work cooling.⁷⁷

Although these structural and physiological changes have been documented in firefighters, we do not know if they are transient or if they contribute to advancement of atherosclerosis. Also, we do not know if these changes would increase the likelihood of COVID-19 severity if COVID-19 infection occurred in temporal proximity to firefighters, but they raise concerns. Furthermore, the long-term effects of COVID-19 are only beginning to emerge, but there is mounting evidence to suggest that a significant portion of individuals with COVID-19 will continue to exhibit symptoms months after they recover from the acute infection. We believe that there is a significant possibility that firefighters who suffer from COVID-19 infection may continue to have vascular dysfunction, including increased coagulability, that is not detected clinically but that could be exacerbated by occupational work of firefighting or that continuing symptoms of fatigue with exertion or shortness of breath may significantly delay return to work.

EPIDEMIOLOGY OF COVID-19 IN US FIREFIGHTERS

There are approximately 1.1 million firefighters in the US, approximately 70% of whom are volunteers. To our knowledge, few studies have formally analyzed the incidence rates of COVID-19 in the U.S. fire service. However, preliminary results from the SFFD COVID-19 Antibody Study⁷⁸ showed that out of 1233 SFFD members tested, only 3 had previous COVID infection (positive antibody test), yet 48% of those surveyed reported likely or confirmed contact with a COVID-19 positive individual. Using a rapid SARS-CoV-2 IgM-IgG antibody test, Caban-Martinez et al⁷⁹ documented an 8.9% seroprevalence positivity rate with both early-stage and late-stage infection in a relatively small (200 members) Florida firefighter workforce. International Association of Fire Fighters (IAFF) and the USFA have continuously tried to update the descriptive statistics of firefighters infected with COVID-19. The IAFF has surveyed local fire department union leadership and have found that over 32,755 firefighters have been exposed, 12,754 have been quarantined, and 6456 have been isolated to date.⁸⁰

National Fire Incident Reporting System distributed a survey as part of COVID-19 Special Study to determine if COVID-19 is a factor, and if so, how severe, during fire responses.⁸¹ The survey study has been in place since January 1, 2020 and has collected roughly 5 million responses from 8236 US fire departments across

all 50 states as of May 16, 2021. Survey results found that 63.5% of respondents reported possible encounters with COVID-19 patients that were due to incidents of rescue and EMS, with only 4.9% of incidents occurring during fires.⁸¹ Out of the total number of responses, only 72,580 (1.46%) encounters with an individual suffering from COVID-19 have been confirmed.⁸¹ However, 210,901 (4.25%) responses suspect an encounter with an individual infected with COVID-19. Furthermore, for 1,414,333 encounters, it is unknown if the individuals the firefighter interacted with had COVID-19.⁸¹ Based on the lack of systematic reporting, and the limitation in the information that is available at the time that firefighters respond to an incident, the number of firefighters infected with the virus, both symptomatic and asymptomatic could be grossly underreported.

It is clear that some firefighters have suffered duty-related deaths due to COVID-19. As of May 16, 2021, the USFA reported that the National Law Enforcement Officers Memorial Fund has identified over 150 firefighter deaths due to COVID-19. It is unclear how many other firefighters have succumbed to the disease, but their deaths are not tracked by the USFA because of a lack of evidence that the infection was duty related.

RECOMMENDATIONS TO FIREFIGHTERS DURING COVID-19 PANDEMIC

Firefighters are often dual trained as emergency medical technicians or paramedics and provide emergency medical care during times of disaster, including a pandemic. Thus, there is potential that the fire service is at an increased exposure risk of contracting the SARS-CoV-2 infection. The fire service is familiar with risk evaluation and mitigation procedures. The IAFF has provided easily accessible recommendation guidelines for the selection, care, and cleaning/sanitation of structural firefighting personal protective clothing while advocating for the use of either single-use, disposable equipment, or dedicated equipment to decontaminate.⁴ The IAFF has also continually advocated for frequent hand washing, social distancing, and the use of serologic testing, molecular testing, and evaluation by a healthcare provider if one has had or is suspicious of having COVID-19.⁴

The IAFC Coronavirus Task Force has also provided an extensive overview of the recommendations available for fire departments during COVID-19.³ Specifically, a fire department's primary answering point should ask all callers seeking emergency medical assistance about whether they are experiencing COVID-19-like symptoms such as a cough, difficulty breathing, fever, and/or body aches.³ This information will then be transferred to the emergency medical staff on call, allowing them to prepare for the interaction by donning the appropriate PPE.³ The Coronavirus Task Force also presents new guidelines in decontaminating and disinfecting EMS materials such as stretchers, as well as fire apparatuses.³ Similar to the Coronavirus Task Force, the IAFC has also implemented policy guidelines for firefighter dispatchers including surveying if radio technicians need medical screening (given their contact with department radios), sanitizing radios between shifts, instituting measures that would situate 911 telecommunicators 6 to 10 ft apart and evaluating whether call takers and dispatchers should be wearing face masks and/or hand protection.⁸²

Other organizations are also seeking to provide guidance for fire departments. For example, The FDSOA has issued new standards on the use of PPE and social distancing at fire stations.⁸³ The FDSOA recommends that at shift changes, firefighters remove and store their own PPE and personal items and limit interaction as much as possible between oncoming and leaving shifts. While at the fire station, guidelines implore firefighters to not congregate in small spaces while adhering to the 6-foot minimum spacing. The guidelines also strongly suggest employees self-screen at home for

symptoms of COVID-19 by providing the fire service an easy to follow self-screen checklist.⁸³

Although guidelines have been formed to decrease the risk of COVID-19 exposure in the fire house and during EMS protocols, firefighters could still be at an augmented risk of contracting COVID-19 due to their occupational exposures. And, new strains of the virus may necessitate a revision of existing protocols to protect members and a sustained vigilance. This occupational group may also be at increased risk of severe forms of COVID-19 due to occupational risk factors.

Lastly, fire departments need guidance and support on COVID-19 vaccination for the workforce. Caban-Martinez et al⁸⁴ conducted a national survey in October 2020 analyzing for COVID-19 vaccine acceptability among firefighters and EMS. They found that among the 3169 firefighters and EMS worker respondents, 48.2% expressed high acceptability of the COVID-19 vaccine when it becomes available, while 24.2% were unsure, and 27.6% reported low acceptability. Given that over a quarter of firefighters/EMS workers will not be taking the vaccine, and another quarter is unsure about taking the COVID-19 vaccines, educational campaigns and strategies to increase awareness, education and training on the use of COVID-19 vaccination in this first responder workforce is needed.

The long-risks of COVID-19 are just beginning to emerge, but there is already convincing evidence that a large number of individuals have persistent symptoms. One study reported that term 86% of patients who were discharged from an Italian hospital had the persistence of at least one symptom after an average of 2 months (most commonly fatigue or shortness of breath).⁸⁵ It is also clear that some individuals exhibit pronounced symptoms that continue for months. Greenhalgh et al⁸⁶ reports that approximately 10% of individuals will continue to have symptoms many weeks or months after the virus is no longer detectable. These individuals are sometimes termed "long-haulers" and their constellation of symptoms has been referred to as Post-COVID syndrome or Chronic COVID. Further, it appears that the likelihood of developing these long-term effects is not related to the severity of COVID-19.⁸⁷ These long-term consequences could impact the ability of firefighters to safely perform work that places considerable strain on the cardiopulmonary system. Myocarditis in the days or weeks after infection²³ could place firefighters at risk if they are returned to work too early. Further, endothelial damage could potentially lead to long-term impairment in the cardiovascular response to the stress of firefighting and lead to an increase in the potential for clot formation. We recommend that research efforts be directed at understanding if firefighters are at increased risk of being infected with SARS-CoV-2, if firefighters are at increased risk of severe complications due to occupational risk profile, and also to investigate the short term (weeks to months) and long-term (months to years) effects of COVID-19 that would be of particular concern to this occupational group that routinely experiences severe cardiovascular disruption in the performance of their duties. The long-term consequences of COVID-19 could have implications on medical evaluations for candidates and incumbents, and for return to work.

CONCLUSION

Because of occupational exposure to individuals with COVID-19, firefighters have an increased risk of being infected with SARS-CoV-2 infection. We have also presented evidence that occupational risks and exposures such as smoke and particulate matter, interrupted sleep patterns, and high levels of sympathetic nervous stimulation that are ubiquitous in the fire service, lead to increased risk of pulmonary function decrements, accelerated CVD, and a high prevalence of risk factors (including CVD risk factors) that place firefighters at increased risk of developing severe forms of COVID-19. We also raise concerns about the long-term consequences of COVID-19 infection in workers who are routinely perform

strenuous work in dangerous environments and that leads to severe cardiovascular disruption. We recommend that the medical providers be alert to potential cardiopulmonary derangements following a positive COVID-19 test and that specific research be done to understand the unique long-term health consequences that COVID may impose on this occupational cohort.

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