Cardiorespiratory Fitness of Firefighters

Initial Results of a Multi-Phased Study

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Objective: To address which body composition (BC) measures best correlate with cardiorespiratory fitness (CRF) in firefighters and develop a model for accurate CRF estimation compared with traditional methods. **Methods:** Career firefighters had body mass index (BMI) and waist circumference (WC) measured in addition to body fat percentage (FM%) by dual-energy x-ray absorptiometry (DXA). CRF as maximum oxygen uptake (VO_{2max}) was estimated by rowing machine and measured by indirect calorimetry in a treadmill exercise test. **Results:** Fifty two firefighters participated (92.3% men). Univariate correlations with BMI were best with WC. Univariate correlations with VO_{2max} were best with FM%. Obesity classifications by BC measures agreed weakly at best. Multivariate analysis of several variables yielded an improved VO_{2max} estimate ($R^2 = 0.70$). **Conclusions:** Fire departments may benefit from more sophisticated measures of BC and CRF to evaluate firefighter fitness.

Keywords: body composition, cardiorespiratory fitness, dual-energy x-ray absorptiometry, firefighters, obesity

F irefighters are exposed to extreme metabolic and cardiopulmonary stressors in the performance of their vocation that are recognized to exceed the actual physical or environmental hazards.[1] The current medical literature regarding firefighting highlights two frequently cited statistics: (1) based on body mass index (BMI), upwards of 73% to 80% of firefighters are considered overweight or obese, and (2) more than 45% of firefighter line-of-duty deaths are due to cardiovascular events.[2]

This finding regarding BMI has been widely reported in the US media after being published in a 2014 article in the journal *Preventing Chronic Disease*.[3] Such a finding is particularly relevant to firefighters given that there are recommended cardiorespiratory performance standards for firefighters, commonly accepted as 12 metabolic equivalents (METs) or maximum oxygen consumption during aerobic exercise (VO_{2max}) of 42 mL O_2/kg of body weight/min.[4] As a consequence, failure to meet such a standard may limit a firefighter's ability to perform (or be employed) in full-duty tasks based on individual fire station requirements, though only 27% of fire departments have been found to have programs focused on fitness and health.[5,6] Few professions, other than elite athletes, require this level of cardiorespiratory fitness (CRF), especially given that full turnout gear weighs approximately 50 pounds. In addition, CRF is increasingly recognized as a vital component of health, wellness, and longevity, and has been argued as an important component of annual clinical evaluation.[7]

While elevated BMI is associated with cardiovascular disease morbidity and mortality, BMI has been demonstrated to be a nonspecific metric of body composition. BMI performs well as a population-level measure but suboptimally as an individual-level measure. The misclassification of younger adults as well as firefighters as overweight and obese based on BMI has been discussed in several studies.[8–12] These studies utilized bioimpedance testing or skin calipers for body fat percentage (fat mass percentage, FM%) measurement, methods known to have significant levels of error in terms of false positives and false negatives. A series of these studies cite a single article with a sample size of 39 individuals as validation of bioimpedance in comparison to dual-energy x-ray absorption (DXA), but also report DXA as the gold standard for FM% measurement.[8–10,13] This inaccuracy of FM% compared with BMI was addressed thoroughly in one study of US firefighters, demonstrating the potential for false positive and false negative identification of obesity in this population.[10] The importance of misclassification of obesity was demonstrated in a systematic review by Flegal et al,[14] where it was reiterated that all-cause mortality is increased in all grades of obesity in combination relative to normal weight individuals, but that in substratification of obesity classification, grade 1 obesity (BMI 30 to less than 35) demonstrated no elevated mortality and overweight (BMI 25 to less than 30) individuals were associated with a lower all-cause mortality.

DXA is a widely-available technology that is relatively inexpensive compared with other diagnostic technologies, is safe, and can accurately measure BF%. DXA studies can be completed in less than 10 minutes and provide data that is valid and reproducible over time. The radiation from a DXA scan is less than that received from routine environmental exposure in a single day. Americans typically receive approximately 3.0 milliSieverts (mSv) of radiation

exposure annually from cosmic radiation, household radon, and other environmental sources. This does not include elective diagnostic imaging sources. The radiation exposure of a DXA scan is ~0.005 mSv, about a tenth of that from a single chest x-ray (CXR).[15] By comparison a CT scan of the pelvis, chest or abdomen can expose the patient to 6.0 to 10.0 mSv in one study (the equivalent of 2 to 3 years of environmental exposure in a single medical study).[16] The precept of As Low As Reasonably Achievable (ALARA) in order to minimize radiation exposure is easily honored in the case of DXA scanning due to the extremely low-dose exposures.[17] Mattila et al[18] have demonstrated the practical utility of DXA in young new male military conscripts with strong prediction of 12-minute running test performance (a surrogate of VO_{2max}) in correlation with FM% and without correlation with BMI.

The misclassification of obesity via BMI is also significant as it pertains to CRF, to the extent that body composition and CRF both have age- and sex-specific changes, yet BMI as a measure is comprised only of height and weight. As a consequence, the need for appropriate BMI reference ranges in the context of age and sex has been identified and has been studied, with FM% changing independently relative to age and sex, regardless of changes in BMI.[19,20] Similarly, the need for VO_{2max} references ranges for CRF relative to age and sex have been discussed and re-evaluated in recent years, as these data can inform population health decision-making, including in the workplace.[21,22] Specifically, physical activity, CRF, and obesity have been demonstrated to impact work performance, absenteeism, and presenteeism.[23] This is significant for firefighters as their recommended CRF standard of 42 mL O_2/kg/min does not account for the age and sex of the firefighter, thus having the potential to misclassify a firefighter as fit or unfit inappropriately.[4]

As such, this study, representing the initial phase of a larger observational study, aimed to address which body composition methods best correlate with CRF in firefighters. This initial phase of the study hypothesized that FM% and lean body mass percentage (lean mass percentage, LM%) correlate higher with measured CRF than traditional body composition methods, such as BMI or waist circumference (WC). Additionally, we hypothesized that these data, in conjunction with rowing machine-based CRF estimates and demographic, employment, physical activity, and medical history data, can comprise an effective means of estimating firefighter CRF.

The second phase of this study will seek to confirm the initial phase findings and, in addition, empirically test the correlations of body composition and CRF metrics with measures of cardiovascular risk. The developed CRF estimate will additionally undergo a cost analysis in comparison to direct measurement of VO_{2max}.

METHODS

This study was a cross-sectional correlational study with individual-level measurements of cardiorespiratory fitness (CRF) and body composition for an urban fire department in the Twin Cities metropolitan area in Minnesota. The study design, methods, and implementation protocols were reviewed and approved by an Institutional Review Board (IRB Project Number A16-667).

Data Collection

All firefighters within the study fire department were sent a study invitation e-mail from their fire department administration via an internal distribution list. Inclusion criteria for the study included current and unrestricted employment within the study fire department and willingness to participate in the study; pregnancy (or anticipated pregnancy) was a primary exclusion criterion due to variations in CRF during pregnancy and the exposure to radiation implicit in the study's design. No financial incentives were offered for participation in the study, however, participants were mailed their results with a brief interpretation of the data from the study physicians after all data were collected and analyzed. Participants

were also offered the opportunity to meet with one of the physician study investigators after receiving their results to review them in a 15-minute individual session.

Study data were collected and managed using REDCap electronic data capture tools hosted at the primary study.[24,25] REDCap (Research Electronic Data Capture, Vanderbilt University, Nashville, NT) is a secure, web-based software platform designed to support data capture for research studies.

Individuals meeting inclusion criteria who responded with interest in the study were placed onto a list and selected for participation in the order of receipt of their response until the initial phase study population size was met. Once the individuals were selected for the study, they were notified via e-mail of their participation and were asked to attend an in-person enrollment and evaluation visit at their local fire department.

The study protocol consisted of three evaluations: (1) enrollment and evaluation at the fire department training facility, (2) a treadmill-based VO_{2max} measurement, and (3) a DXA scan for body composition measurement. These three evaluations were scheduled to occur on separate dates, and the second and third evaluations could occur independent of the scheduling of the other.

The enrollment and evaluation visit consisted of completing informed consent for the study, completing a demographic survey, having simple body composition measurements taken, and undergoing a 2000 m rowing test (Concept 2, Morrisville, VT). The demographic survey recorded information on the participant's employment history, smoking history, and physical activity according to the Nord-Trøndelag Health Study (HUNT 2) physical activity questionnaire.[26] The initial evaluation included measurement of height, weight, WC, and resting heart rate. WC was measured using the iliac crests and midaxillary lines as landmarks in accordance with National Health and Nutrition Examination Survey (NHANES) procedures.[27] Participants' completion times of the 2000 m rowing test were recorded.

VO_{2max} was estimated using two calculations provided by the rowing machine manufacturer for self-identified "highly-trained" (specified as "training level: high") and "non-highly-trained" ("training level: low") populations.[28] Because the definition of "training level" is subjective, both of these estimates were calculated for this study. The estimate equations compute VO_{2max} as $(Y \times 1000)$/weight, where Y is calculated differentially based on training level (high vs low) and sex, and in the highly-trained calculation including a binary classification of weight at or below 61.36 kg in women or 75 kg in men. These VO_{2max} estimate equations are reported as based on mask-based indirect calorimetry measurements using rowers from the same manufacturer.

Participants were then scheduled at a local health promotion clinic (Health Strategies, White Bear Lake, MN) with appropriate equipment and facilities to complete mask-based measured VO_{2max} testing using indirect calorimetry. VO_{2max} was measured with a CardioCoach (KORR Medical Technologies, Salt Lake City, UT) while participants underwent a treadmill-based Bruce protocol.[29] Data were collected on-site and securely transmitted to the study database.

Participants were additionally scheduled to undergo a DXA scan at a local clinic within a large health system. Women participants were offered the opportunity to undergo urine pregnancy testing at the time of this scan if their pregnancy status was not known. Whole-body DXA scans were acquired on a Hologic Horizon W system (Hologic Inc., Marlborough, MA). All scans were conducted by a radiologic technologist using Hologic APEX software (version 5.6.0.4) with body composition calibration correction based on data from NHANES enabled. Calculation of body composition metrics without NHANES body composition calibration correction was performed during data analysis due to recent demonstration of FM% overestimation with use of the NHANES body composition calibration correction.[30]

Data Analysis

Classifications of VO_{2max} (relative to an individual's size, expressed as mL/kg/min, as opposed to absolute VO_{2max} measured as L/min), and classifications of obesity by BMI, WC, FM%, were applied according to reference tables published by the American College of Sports Medicine (ACSM), which classify these measures according to age and sex for VO_{2max} and FM%, and by sex for WC.[31]

The ACSM classifies BMI as "underweight," "normal," "overweight" (BMI 25.0 to 29.9), and "obese" (BMI more than 30.0); WC as "very low," "low," "high" (90 to 110 cm), and "very high" (more than 110 cm); and FM% as "very lean," "excellent," "good," "fair," "poor" (between the 40th and 20th percentiles for age and sex), and "very poor" (below the 20th percentile for age and sex). To evaluate agreement of obesity classifications for various body composition measures, a sensitivity analysis was performed by constructing two classifications of obesity with differential sensitivity—more and less likely for an individual to meet the obesity classification—for each of BMI, WC, and FM%. Obesity classifiers for BMI were labeled as BMI1 ("overweight" or "obese") and BMI2 ("obese"), for WC as WC1 ("high" or "very high") and WC2 ("very high"), and for FM% as FM1 ("poor" or "very poor") and FM2 ("very poor").

Statistical Analysis

Continuous variables were visually inspected for extreme outliers and deviation from normal distribution using Q–Q plots. To evaluate correlation of BMI with other body composition metrics (WC, total fat mass [TFM], FM%, total lean mass [TLM], LM%), Pearson correlation coefficients were calculated. Agreement of obesity classifiers was measured with the Cohen (unweighted) κ coefficient, and sensitivity and specificity of obesity as a classifier were computed, using two classifications of obesity for each of BMI (BMI1 and BMI2), WC (WC1 and WC2), and FM% (FM1 and FM2).

Simple linear regression was performed for measured VO_{2max} as a dependent variable, and estimated VO_{2max} rower-based "highly-trained" and "not highly-trained" metrics, body composition metrics, and demographic variables as independent variables. A multivariate regression analysis was conducted against measured VO_{2max} using non-collinear demographic, body composition, and VO_{2max} rower-based estimates to evaluate performance of this model in accurately representing VO_{2max}.

Statistical analyses were performed using SAS v9.4 software (SAS Institute Inc., Cary, NC). A *P* value (alpha) of 0.05 was considered statistically significant.

RESULTS

A total of 52 firefighters were enrolled, 48 men, 4 women (92.3% men), with 100% completion of all three evaluation components of the study. The mean age of participants was 42.8 (±8.1) years. All participants were full-time firefighters (100%), and 63.5% had a second employment. Participants could select multiple racial designations, and 84.6% of the firefighters were White, 9.6% Hispanic, 7.7% Other, 3.9% Black, 1.9% Asian. Only two individuals reported current smoking (3.9%), but less than daily; the remaining 96.1% do not currently smoke. Of all individuals, 75% reported never smoking regularly. Physical activity was

TABLE 1. Body Composition Measures for Males and Females, Including Categorization of Waist Circumference and Percentile Age-Stratified Categorization of Percent Fat Mass by Sex

Measure	Units /Range	Male Number/Mean	Male ±SD/%	Range	Female Number/Mean	Female ±SD/ %
Enrolled		48			4	
Body composition measures						
Height	cm	181.1	6.5		169.8	7.6
Weight	kg	94.6	13.9		75.2	8.6
Body mass index[*]	kg/m^2	28.9	3.9		26.0	2.1
Normal (18.5 to <25)		5	10.4%		1	25.0%
Overweight (25 to <30)		11	66.7%		3	75.0%
Obese (≥30)		32	22.9%		ND	ND
Waist circumference[†]	cm	98.9	10.3		89.1	3.8
Low	70 to <90	31	64.6%	80 to <100	2	50.0%
High	90 to <110	15	31.3%	100 to <120	2	50.0%
Very high	≥110	2	4.1%	>120	ND	ND
Body composition measures by DXA						
Body mass, total	kg	92.7	13.3		74.0	7.1
Fat mass, total	kg	22.4	8.1		19.6	5.0
Fat mass, percent	%	23.6	5.7		26.1	4.7
Very poor (<20th %ile)		14	29.2%		ND	ND
Poor (20–39th %ile)		11	22.9%		2	50.0%
Fair (40–59th %ile)		9	18.8%		ND	ND
Good (60–79th %ile)		11	22.9%		2	50.0%
Excellent (80–94th %ile)		2	4.1%		ND	ND
Very lean (≥95th %ile)		1	2.1%		ND	ND
Lean mass, total	kg	67.2	7.4		51.8	2.3
Lean mass, percent	%	72.9	5.4		70.3	4.6
Bone density measures by DXA						
Bone mineral content, total	kg	3.2	0.4		2.7	0.4
Bone mineral density, total	g/cm^2	1.3	0.1		1.3	0.1
T-Score		1.2	1.0		2.1	1.2
Z-Score		1.2	0.9		1.8	1.0

ND, no data.

[*]No participants had "Underweight" body mass index (less than 18.5 kg/m^2).

[†]No participants had "Very Low" waist circumference (less than 70 cm for men, or less than 80 cm for women).

TABLE 2. Correlation of Non-body Mass Index (BMI) Body Composition Measures With BMI

Body Composition Measure	Correlation Coefficient With BMI
WC	0.87
Total FM	0.83
Total LM	0.64
FM (%)	0.62
LM (%)	−0.61

FM, fat mass; LM, lean mass; WC, waist circumference.

evaluated by the HUNT 2 physical activity assessment and 88.2% reported over 3 hours per week of light physical activity, and 65.4% reported over 3 hours per week of heavy physical activity. No regular prescription medication use was reported by 34 individuals (65.4%). Twenty nine of the 52 firefighters (55.8%) opted to meet with a physician study investigator to individually review their results.

Body composition measures are detailed in Table 1. For men, mean BMI (kg/m^2) was 28.9 (±3.9), which corresponds to being overweight; waist circumference (cm) was 98.9 (±10.3), which corresponds to the category of low waist circumference. Mean FM% as measured by DXA scan was 23.6% (±5.7), and was distributed between the very poor, poor, and fair categories, stratified by age. For women, mean BMI (kg/m^2) was 26 (±2.1), which corresponded to being overweight; waist circumference (cm) was 89.1 (±3.8), which corresponded to the category of low waist circumference. Mean FM% as measured by DXA scan was 26.1% (±4.7), and was distributed between the fair, good, and excellent categories, stratified by age.

Correlation coefficients of BMI with other body composition measures yielded strong correlations with WC (0.87) and TFM (0.83), but otherwise only moderate correlations with the remaining variables (Table 2).

VO_{2max} was underestimated by 8.0 to 9.6 mL/kg/min (17.1% to 20.5%) in men and 6.5 to 7.3 mL/kg/min (15.7% to 17.7%) in women using the Concept 2 rowing VO_{2max} estimates when compared with measured VO_{2max} by treadmill test (Table 3). Univariate linear regression of VO_{2max} for highly- and non-highly-trained rower-based estimates were compared against measured VO_{2max} and are shown in Fig. 1.

Univariate linear regression of body composition measures (BMI, WC, FM%, LM%) with measured VO_{2max}, demonstrated at best a moderate goodness-of-fit for FM% and LM%, both of which

had a R^2 of 0.58. BMI and WC had worse fits with VO_{2max}, with R^2 of 0.27 and 0.32, respectively (Table 4). In addition, univariate models of demographic variables and VO_{2max} estimates were considered, demonstrating statistically significant associations ($P < 0.005$) with $R^2 = 0.63$ for VO_{2max} of non-highly trained subjects, $R^2 = 0.21$ for BMC, $R^2 = 0.09$ for age, and $R^2 = 0.07$ for heavy physical activity based on the HUNT 2 questionnaire.

Evaluation of sensitivity, specificity, and agreement of classifiers of obesity by Cohen κ between FM%, BMI, and WC were conducted with mixed results, with at best only moderate agreement ($\kappa = 0.57$) of obese BMI (BMI2) and very poor FM% (FM2; Fig. 2).

A multivariate regression model of estimated VO_{2max} was constructed from a conjunction of demographic, body composition (BMI, BF%, LBM%, WC), and VO_{2max} rower-based estimate variables based on their performance in univariate models. The best-fit and statistically significant measures included in the model while excluding collinear variables (such as for various body composition measures or VO_{2max} estimates) included rower-based non-highly-trained VO_{2max}, FM%, BMC, age, and heavy physical activity (HUNT 2), yielding a model with $R^2 = 0.7$.

DISCUSSION

This study successfully demonstrates that various selected body composition measures of firefighters are not well-correlated. In agreement with prior studies, WC is somewhat correlated with BMI in firefighters, but to a lesser degree with FM%, and these divergences can lead to false positive (erroneous attribution of obesity) and false negative (erroneous attribution of non-obesity) in firefighters.[8–11,32] This finding of BMI and WC being more highly correlated with each other than with FM% has also been reported in over 12,000 adults in the general population using NHANES data and DXA for FM% measurement.[33] Implications of such erroneous classifications include the notion that obesity may be associated with poor CRF and non-obesity associated with adequate CRF among firefighters.

A striking finding of this study is that classifications of obesity did not agree well with each other unless characterizing a very obese population, and even then, correlations appeared to be moderate, an observation corroborated by Choi et al.[32] This suggests that BMI as a stratifying metric of obesity in this population may be misleading. Despite the simplicity of measuring BMI, the strength of correlation with cardiorespiratory fitness (CRF) in firefighters may be weak.

Of the many body composition measures studied, VO_{2max} is best (yet imperfectly) predicted by FM%, an observation that is in agreement with Kiss et al,[34] though their results demonstrated a lesser degree of goodness-of-fit for FM% and VO_{2max}, and a nearly

TABLE 3. VO_{2max} Measures and Estimates in Males and Females, Including Percentile Age-Stratified Categorization of Measured VO_{2max} by Sex

VO_{2max}, mL/kg/min	Male			Female		
	Mean	±SD	Percent Change from Measured VO_{2max}	Mean	±SD	Percent Change from Measured VO_{2max}
Treadmill, measured	46.9	8.4	———	41.3	5.6	———
Very poor (<20th %ile)	1	2.1%		ND	ND	
Poor (20–39th %ile)	6	12.5%		ND	ND	
Fair (40–59th %ile)	7	14.6%		ND	ND	
Good (60–79th %ile)	10	20.8%		1	25.0%	
Excellent (80–94th %ile)	18	37.5%		ND	ND	
Superior (≥95th %ile)	6	12.5%		3	75.0%	
C2, not highly-trained	37.3	7.9	−20.5%	34.8	4.1	−15.7%
C2, highly-trained	38.9	7.9	−17.1%	34.0	7.2	−17.7%

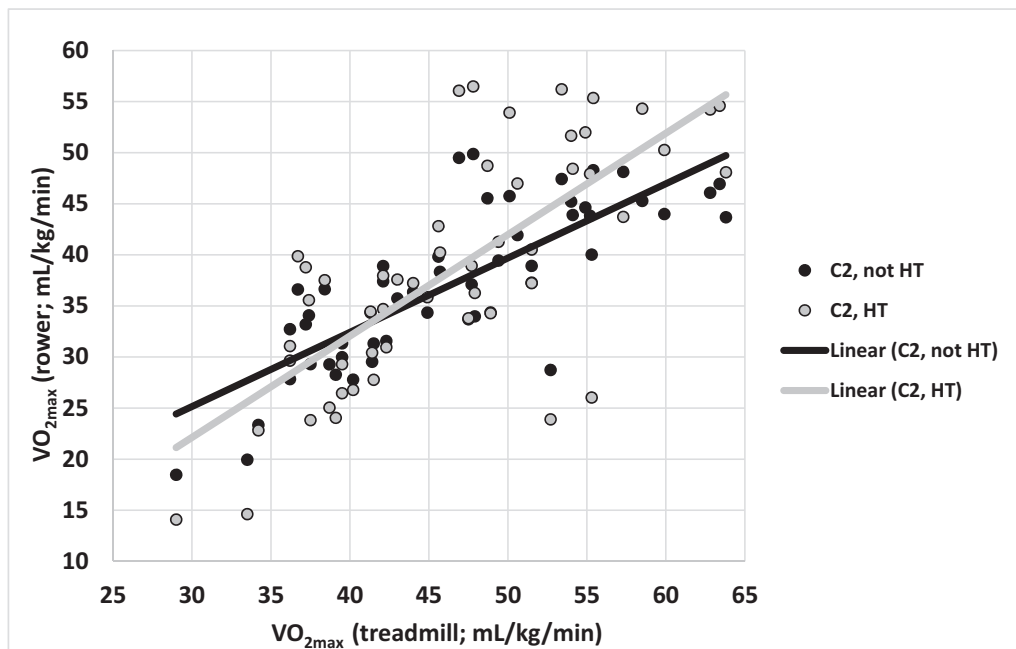C2: Concept 2 rowing machine VO_{2max} estimates.

FIGURE 1. Univariate linear regression of VO_{2max} estimates against measured VO_{2max}. C2, Concept 2 rowing machine VO_{2max} estimates, classified as not highly-trained or highly-trained; HT, highly-trained, not HT, not highly-trained.

equivalent goodness-of-fit for BMI and VO_{2max}. This finding confirms the study hypothesis that FM% is a more valid measure of body composition and more predictive of CRF than BMI. This study is relatively unique amongst investigations regarding body composition in firefighters to the extent that it includes body composition measurements by DXA (a research need noted by Poston et al[8]), as well as correlating these more precise body composition measures with CRF. A similar study correlating body composition and measured VO_{2max} was performed in Belgian firefighters, where a "strong" association between FM%, BMI, and VO_{2max} was noted, though this study may not be generalizable to United States firefighters, who have arguably quite different social and dietary pressures that may affect their weight.[34] However, our results diverge from another similar study using a VO_{2max} estimate and skin caliper-based BF% measurements, which concluded that BMI is an adequate method of estimating body composition in firefighters, but limited its conclusions to the extent of noting the evident inverse association between a VO_{2max} and BMI.[35] A very recent study by Barry et al[36] evaluating the correlation between WC

and VO_{2max} found a stronger statistically significant correlation (−0.55) than this study, with a similar R^2 of 0.30.

In evaluating existing VO_{2max} estimates from the Concept 2 rower, this study found that the rower-based estimates underestimated VO_{2max}, compared with measurements that were obtained with the gold standard treadmill test with indirect calorimetry. These rower-based VO_{2max} estimates had better correlation with measured VO_{2max} using the "non-highly-trained" estimate as compared with "highly-trained" estimate. As estimates of VO_{2max} may not adequately represent the true measurement, the developed multivariate model ($R^2 = 0.7$) integrating body composition measures and VO_{2max} estimates, in addition to other variables, can more accurately evaluate CRF. These data support continuing this study in an expanded sample size to develop a more robust model of VO_{2max}, integrating additional VO_{2max} estimates such as those implemented in the Survey of Activity, Fitness, and Exercise (SAFE) study and the third phase of the Nord-Trøndelag Health Study (HUNT-3), where VO_{2max} has been estimated using simple questionnaire-based tools.[37,38]

A unique aspect of the study was providing the results to study participants, which historically has been a rare feature of research studies, though contemporary research methods support changing this paradigm for many reasons.[39] Although not formally measured, informal feedback from study participants regarding this aspect of the study was wholly positive, and suggestive that reviewing such information may be a motivating factor in behavioral change; this feature can be evaluated more formally in future validation studies implementing this VO_{2max} model longitudinally and alongside potential interventions to improve fitness indicators. Such future research is aligned with the need for supporting wellness in the fire service on the part of the individual, leadership, and department, including measures of body composition and CRF, as identified as part of the Wellness-Fitness Initiative developed by the International Association of Fire Fighters and the International Association of Fire Chiefs.[40]

A primary limitation of this study is the bias implicit in volunteer-based recruitment, to the extent that those participating in

TABLE 4. Univariate Linear Regression Coefficients (β Coefficients) and Goodness-of-fit (R^2) for Body Composition Measures Against Measured VO_{2max}

Body Composition Measure	β Coefficient	R^2
FM (%)	−0.32	0.58
LM (%)	+0.34	0.58
Total FM	−0.20	0.51
WC	−0.13	0.32
BMI	−0.32	0.27
Weight	−0.07	0.18
Total LM	−0.01	0.002

All regressions were statistically significant ($P < 0.005$) except total LM. BMI, body mass index; FM, fat mass; LM, lean mass; WC, waist circumference.
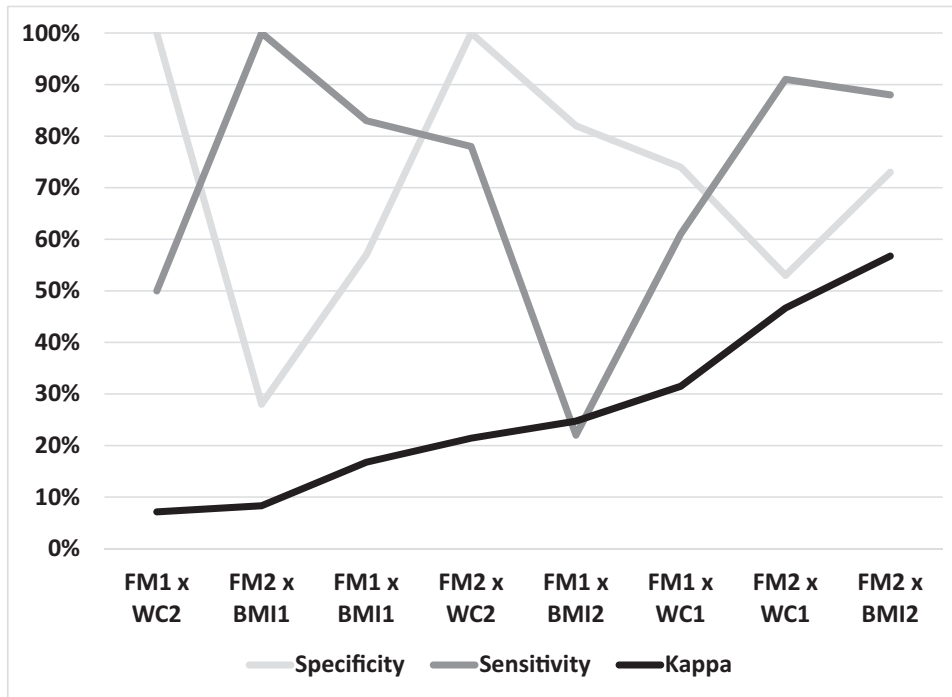
FIGURE 2. Performance metrics (specificity, sensitivity, κ coefficient) of classification of obesity by body mass index (BMI), waist circumference (WC), and percent fat mass (FM). BMI1: classification in "overweight" or "obese" BMI categories; BMI2: classification in "obese" BMI category; WC1: classification in "high" or "very high" WC categories; WC2: classification in "very high" WC category; FM1: classification in "poor" or "very poor" FM categories; FM2: classification in "very poor" FM category.

the study may represent those already motivated to evaluate their body composition and CRF, as noted by the larger prevalence of higher percentile CRF noted in Table 3. However, in terms of body composition, 89.6% of men and 75.0% of women in this study were overweight or obese according to BMI, consistent with prior reports of firefighters, while only 35.4% of men and 50.0% of women had high or very high WC. The average BMI of 28.9 kg/m^2 and WC of 98.9 cm for men in this study are relatively consistent with the reported averages of 28.6 kg/m^2 and 97.3 cm reported in male career firefighters by Poston et al,[8] in which they reported 97% participation of solicited firefighters, suggesting that the degree of obesity represented in this study may be consistent with the career firefighter population despite a volunteer bias. Conversely, the same Poston et al[8] study identified estimated VO$_{2max}$ by physical activity as quite different in obese (BMI more than or equal to 30) versus non-obese firefighters, which may indicate that inclusion of more obese and less fit firefighters could impact the applicability of this study's findings in such a population, with likely better convergence of body composition measures.

In addition, the small sample size of this study, particularly with respect to women (7.7%)—although greater than the proportion of women career firefighters in the fire service nationally, that is, 4%—may limit generalizability in terms of representing anthropomorphic and cardiorespiratory variability.[41] Lastly, the composition and culture of career firefighters in an urban, metropolitan setting, varies from department to department, and similarly limits generalizability across departments, and can be addressed in future studies validating this model across multiple fire departments of various settings.

Whereas this study is limited to career firefighters, Martin et al[42] evaluated obesity and CRF in volunteer firefighters and concluded that "the majority of volunteer firefighters may possess . . . inadequate physical fitness," which may limit the generalizability of this study's findings where most firefighters had relatively high CRF. However, prior studies in volunteer firefighters have addressed the same limitations as this study of BMI in assessing obesity, with the Poston et al[8] study previously discussed showing

similar VO$_{2max}$ in non-obese career versus volunteer firefighters as opposed to divergent VO$_{2max}$ in obese versus non-obese firefighters, regardless of career or volunteer status.[11] These inconsistencies suggest further work on evaluating body composition measures and CRF to be done in the volunteer population, where risks may be greater.

Future work in the second phase of this study will also assess whether VO$_{2max}$ estimates can correlate well with measures of cardiovascular risk in this population, thereby increasing the utility of these estimates in monitoring the risk and fitness of this at-risk population, which has been identified as a needed area of research to understand the relationship of these two variables.[43] The second phase of this study will also evaluate the cost-effectiveness of the measures comprising the multivariate model to validate feasibility of implementing this sort of VO$_{2max}$ evaluation in a firefighter population.

CONCLUSIONS

Traditional body composition measures, such as BMI, may suffer from measurement error that makes the evaluation obesity inappropriate for some subpopulations, such as firefighters. Considerations of CRF as a function of obesity will, as a result, be similarly problematic. Body fat percentage can more accurately estimate obesity, and can be easily measured with widely-available and safe DXA technology. Using demographic measures and more accurate measures of body composition conjoined with estimates of CRF, this study developed a preliminary multivariate model that improved prediction accuracy of CRF over other existing estimation methods. Future work can validate this model in a larger population of firefighters or in the general population to improve precision and evaluate cost-effectiveness.

ACKNOWLEDGMENTS

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