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Wildland Firefighting: Adverse Influence on Indices of Metabolic and Cardiovascular Health

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Abstract

Objective: The purpose of this study was to evaluate pre- and post-season measures of body composition, skeletal muscle, and blood parameters/liver lipid in wildland firefighters (WLFF) over the fire season.

Methods: Alaskan WLFF (N=27) crews were evaluated pre and post wildfire season, which included 63±10 operational days. Body composition, thigh muscle area and liver lipid were quantified using dual energy x-ray absorptiometry and MRI, respectively. Blood metabolic and lipid panels were also collected and analyzed.

Results: Total body, fat, and visceral fat mass increased from pre to post season ($p<0.05$). Total cholesterol, LDL and total globulin also increased ($p<0.05$). There was a trend ($p=0.06$) towards an increase in IHL.

Conclusions: The observed maladaptive changes in adipose tissue, blood lipids and hepatic function may reflect adaptations/consequences to occupational demands/conditions and warrant evaluation of appropriate countermeasures.

Keywords

wildland firefighter; metabolic; intrahepatic lipid; cholesterol; body composition

Introduction

Approximately 6 million wildfires have burned almost 10% of the United States in the past 60 years (1). Above average temperatures throughout the Pacific Northwest combined with population growth have complicated the suppression of wildfires. Since 2002, 6 percent of 4 western states have been burned by wildfires that were primarily caused by lightning, but also influenced by human activity (2). The climate related events have a multifactorial

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impact on human health with workers in agriculture, construction, transportation and firefighters being particularly vulnerable to occupational health risks (3).

Wildland firefighters (WLFF) are positioned at a challenging nexus that balances the protection of life, resources and property against risks to their own health (4). These relationships are complicated by work conditions that can contribute to periods of negative energy balance and variations in dietary intake (4). While several studies have provided data across a range of individuals that suggest work rates analogous to three times that of resting metabolic status (5,6), work output varies substantially between training, ingress and egress (7). Variations in daily work rate and nutrient availability may contribute to oscillations in energy balance (7–9). In fact, a recent meta-regression from nine separate studies suggested that extreme circumstances may foster a negative energy balance beyond the physiological capacity to maintain skeletal muscle, resulting in decreased physical performance (10). Given the importance of skeletal muscle in this scenario, evaluations of seasonal changes in skeletal muscle in WLFF using the precision of magnetic resonance imaging would be beneficial (11).

Wildland firefighting may be often comingled with sleep deprivation that increases the risk of injury and metabolic disease (12). Even though physical performance does not seem affected by sleep deprivation during simulated wildland firefighting (13), detrimental alterations in acute inflammatory responses have been described (11). The number of days “on fire” and the severity of the fires can contribute to additional challenges in this regard as well (14). Physiological strain, negative energy balance, sleep deprivation may not only increase the acute health risks (15,16), but sleep duration of less than 5 hours has been linked to a 50% increase in the incidence of metabolic syndrome (17). The Environmental Protection Agency has also suggested that exposure to wildland fire smoke may pose significant health risks but the overall impact on physiological and/or cardiovascular indices in WLFF have not been well described in a field setting (18). Therefore, the objective of the present study was to examine seasonal alterations in body composition, cross-sectional area of the upper thigh muscles (XT), intrahepatic lipid (IHL), and blood lipids in Alaska WLFF over the summer season of 2017.

Methods

Following approval by the University of Alaska Fairbanks (UAF) Institutional Review Board, WLFF were recruited from the Chena, Midnight Sun, and North Star Hot Shot crews, and the UAF wildland fire crew (overall n=27, 25 M, 2 F, 27±1 years). Study participants completed two visits that included measurement of body composition, XT, IHL and blood lipids that corresponded with pre- and post-fire season during late June through early September of 2017. Following the fire season, participants returned to the laboratory within 72 hours of their return to Fairbanks, AK. Blood sampling and analysis was completed by LabCorp, Inc according to Clinical Laboratory Improvement Amendments from the Federal Food and Drug Administration.

We utilized dual energy x-ray absorptiometry scans (General Electric iDXA, Boston, MA) to measure fat mass (FM) and lean tissue mass (LTM). The XT and IHL measurements were imaged using a Toshiba Excelart/Vantage 1.5 T magnetic resonance imaging/spectroscopy system (Canon, Õtawara, Tochigi, Japan). Axial and coronal T1-weighted images were acquired using a Field Echo sequence (TR=172ms, TE=4ms), and axial T2 images were acquired with a Fast Spin Echo sequence (TR=3700ms, TE=90ms). Seven of the axial T1-weighted images (FOV=30×30cm, matrix 256×256, NAQ=2) were selected based on the half-way point of the femur or between the superior border of the patella and the greater trochanter during each visit. These images were analyzed using Osirix software (Pixmeo, Bernex, Switzerland).

For the measurement of IHL, participants were placed in a prone, head-first position in the whole body coil of the MRI system. Axial and coronal T1-weighted images were acquired using a Field Echo sequence (TR=172ms, TE=4ms), and Axial T2 images were acquired with a Fast Spin Echo sequence (TR=3700ms, TE=90ms, FOV=30×50cm). Spectra were acquired on a 3×3×2cm voxel using a PRESS sequence (TR=2000ms, TE=136, NAQ=256).

Raw data from the spectra including an un-suppressed water reference were converted to ascii format using a custom script, before analysis using JMRUI. All spectra were Fourier transformed, phased and referenced (1.4ppm for lipid spectra, 4.8ppm for water reference). The results from both the lipids spectra and water reference spectra were then used to calculate a lipid-to-water ratio.

Statistical Analysis.

Data were analyzed using Microsoft Excel, iDXA, Osirix, and Prism 5 software. Regular paired t-tests were utilized to compare differences in pre-season and post-season data. Statistics were considered significant with a P-value of less than 0.05. Data are presented as means±SD.

Results.

Clinical characteristics. We enrolled 27 participants who spent 63±10 days on wildfire assignments. Ten participants failed to complete all data collection for their blood panels and molecular imaging due to limited post-season availability and/or crew dispersion.

Body/Tissue Composition (n=27). Total body mass, total FM, arm FM, leg FM, and visceral FM increased from pre- to post-season (P<0.05) (Table 1). There were no changes in total LTM, arm LTM and leg LTM (P>0.05) (Table 1).

Molecular Imaging (n=17). There were no changes in XT from pre- to post-season (P>0.05) (Table 1). There was a strong trend (P=0.06) supporting an increase in IHL (0.143±0.0040 to 0.236±0.0050 lipid/water from pre- to post-season, respectively (Figure 1).

Blood Parameters (n=17). There was an increase in total cholesterol and LDL-cholesterol from pre- to post-season (P<0.05) (Table 2). VLDL-cholesterol and HDL-cholesterol remained unchanged (P>0.05). There were no changes in glucose, blood urea nitrogen, creatinine, estimated glomerular filtration rate, creatinine ratio, sodium, potassium chloride, carbon dioxide, and calcium (P>0.05) (Table 2). There were no changes in albumin, bilirubin, alkaline phosphatase, alanine aminotransferase, and aspartate aminotransferase

($P>0.05$), but there was an increase in globulin and a decrease in albumin/globulin ratio and direct bilirubin ($P<0.05$) (Table 2).

Discussion

The main finding of this study was that WLFF experienced a decline in indices of metabolic and cardiovascular health over the course of the fire season. Evidence for this assertion has been provided by an increase in total plasma cholesterol, LDL-cholesterol, VLDL-cholesterol and an increment in IHL. Perturbations in hepatic function were also evidenced by an increase in globulin and a decrease in albumin/globulin ratio and direct bilirubin. The deterioration in the metabolic biomarkers occurred despite the preservation of skeletal muscle as indicated by no changes in LTM or XT. In many ways, these data may seem surprising given the arduous work previously reported in wildland firefighters on assignment (4–6). Despite potentially challenging circumstances where sustained negative caloric balance might increase the risk of muscle loss (10), the retention of skeletal muscle in our research participants may have been positively influence by the anabolic influence of activity on protein synthesis (19). Alterations in dietary intake, stress responses, smoke exposure and/or a potential detraining effect may be responsible for the observed dysregulation of lipid metabolism (17, 18).

Previous studies in WLFF have demonstrated levels of total energy expenditure (TEE) that reach of 2,719–6,260 kcals/day (6). Energy expenditure from physical activity (EEA) alone may reach as high as 3,900 kcals/day after subtracting basal metabolic rate and dietary induced thermogenesis (6). Even though TEE or total energy intake (TEI) was not measured in the current study, this cohort typically demonstrates high rates of EEA across diverse assignments (5–7). In another study recently performed in our laboratory in backcountry hunters over the course of 12 unsupported days, a similar level of energy expenditure and negative energy balance led to dramatic improvements in metabolic health (20). These results suggest that the level of physical exertion demonstrated in previous field studies involving substantial EEA should lead to favorable changes in metabolic outcomes.

There have been considerable efforts directed towards ensuring adequate nutrient provisions for WLLF. For example, an “eat on the move” strategy has been suggested to help optimize physical performance, reaction time and mood status (21). Using a combination of video dietary intake documentation and an estimation of energy expenditure via wearable technology at different times during the day, recent studies have suggested higher levels of energy expenditure during the entry to the project fire (ingress phase) than the exit from the project fire (ie., egress phase) of the operation in Canadian WLFF (22). These findings were generally consistent with previous work suggesting chronic levels of negative energy balance (4–6). It is somewhat unexpected that our participants actually gained weight, FM and visceral FM in conjunction with detrimental alterations in blood and tissue lipid. Without the existence of a negative energy balance required for improvements in lipid metabolism (23), the perturbation in lipid metabolism would be anticipated. We suggest that the findings in our present study may be potentially indicative of reduced physical exertion and/or increased access to nutrients overall and/or during the egress element of the season.

These findings should not be generalized to all WLFF as the conditions and occupational requirements may vary widely depending on multiple circumstances.

The influence of smoke exposure may have also contributed to the increased risk of metabolic abnormalities with numerous chemicals of potential concern identified in a 2004 report (24). Short- and long-term exposure to ambient air pollutants such NO_2, O_3, and $PM_{2.5}$ have been linked to a reduction in insulin sensitivity and an increase in atherogenic blood lipids (25). While occupational risk factors cannot be singled out, maladaptive changes may be influenced by smoke-induced pro-inflammatory and/or oxidative stress responses in combination with chronic stress, insufficient sleep and/or a high fat diet (26). The influence of sleep deprivation alone may negate the protective role of sleep against chronic elevations in cortisol that have been linked to adverse health outcomes (26). The decrease in direct bilirubin is also consistent with oxidative stress and chronic inflammation (27). Overall, the combined influence of environmental and nutritive factors has been linked to elevations in visceral adipose tissue and the accumulation of IHL (28–29), and complicate the interpretation of these data.

Previous studies have demonstrated that wildland fire suppression represents work that requires 2–3 times more calories that many individuals consume over the course of a day. Our data demonstrate an occupational physical activity paradox where the benefits of exercise on lipid metabolism and hepatic function (30) may be negatively overshadowed by alterations in nutrient delivery, smoke exposure, chronic stress and insufficient sleep (17). In addition, high levels of smoke exposure may be particularly detrimental to human health (31). The interplay between these variables present a continuum with regard to metabolic health instead of a “one size fits all” paradigm. Based on the findings of the present study, we suggest that additional investigative efforts are needed to evaluate the influence of four primary factors: a) physical exertion, b) diet, c) stress and sleep deprivation, and d) smoke exposure on metabolic health, and how these factors may differ depending on assignment and factors mentioned above.

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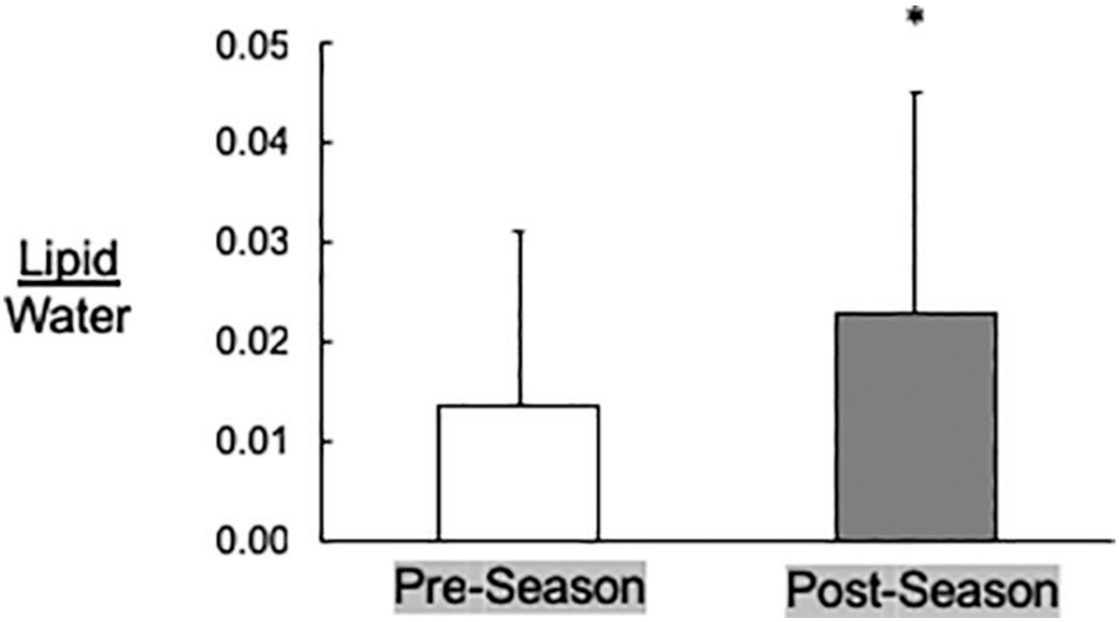

Figure 1.

Pre- and post-season intrahepatic lipid as measured by magnetic resonance imaging/spectroscopy (n=17). *P=0.06. Data = mean±SD.

Table 1.

Body composition and MRI derived data

	Pre	**Post**
Weight	78.7±12.8	79.7±12.3 [*]
Body mass index (kg/m^2)	23.9±2.7	24.5±2.7 [*]
Total fat mass (kg)	12.4±5.2	13.9±4.9 [*]
Total lean mass (kg)	62.8±9.1	63.1±8.7
Lean to fat ratio	5.9±2.5	5.0±1.4
Arm - fat (kg)	1.4±0.6	1.5±0.6
Arms – lean (kg)	8.5±1.4	8.6±1.5
Legs - fat (kg)	4.0±1.8	4.8±1.7
Legs - lean (kg	21.7±3.6	21.9±3.7
Torso - fat (kg)	6.1±3.0	6.7±2.9
Torso - lean (kg)	29.0±4.6	29.2±3.7
Relative skeletal muscle index (kg/m^2)	9.3±1.1	9.3±1.1
Visceral fat (kg)	318±47	419±48 [*]
Upper Thigh Muscle (cm^3)	152.2±24.6	151.8±21.2

Data are presented as means±SD.

[*] Represents significant difference ($P<0.05$).

Table 2.

Lipid, Metabolic and Hepatic Blood Panels

	Pre	Post
Total cholesterol	161.8±28.1	179.9±33.5 *
LDL-cholesterol	85.7±22.5	100.3±31.5 *
VLDL-cholesterol	18.4±10.7	21.8±8.1
HDL-choleseterol	54.7±18.9	57.5±15.7
Triglycerides (mg/dL)	91.8±53.5	109.6±41.2
Glucose (mg/dL)	87.0±5.7	89.3±7.2
Blood urea nitrogen (mg/dL)	15.5±5.7	16.1±4.1
Creatinine (mg/dL)	0.9±0.2	1.0±0.1
Estimated Glomerular Filtration Rate (mL/min/1.73)	109.4±14.2	106.9±12.6
Blood urea nitrogen/creatinine ratio	16.8±3.7	16.9±3.4
Serum sodium (mmol/L)	140.8±1.3	134.9±23.1
Serum potassium (mmol/L)	4.4±0.3	4.5±0.3
Total carbon dioxide (mmol/L)	24.5±1.7	24.5±1.5
Serum calcium (mg/dL)	9.5±0.3	9.5±0.3
Serum total protein (g/dL)	6.8±0.3	6.9±0.3
Serum albumin (g/dL)	4.6±0.2	4.5±0.2
Total globulin (g/dL)	2.3±0.3	2.3±0.3 *
Albumin/globulin ratio	2.1±0.2	2.0±0.3 *
Total bilirubin (mg/dL)	0.6±0.3	0.5±0.3
Alanine aminotransferase (IU/L)	27.2±12.3	28.0±12.6
Aspartate aminotransferase (IU/L)	31.8±12.4	26.1±5.8
Alkaline phosphatase (IU/L)	65.8±15.0	64.3±15.4
Direct bilirubin (mg/dL)	0.15±0.07	0.13±0.06 *

Data are presented as means±SD.

* Represents significant difference ($P<0.05$).