

Steady State Hydration Levels of Career Firefighters in a Large, Population-Based Sample

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Objectives: To establish the extent of steady state hypohydration among firefighters and examine factors associated with their hydration status. **Methods:** Data on 450 career firefighters from 11 randomly selected fire departments had their body composition, total body water (TBW), and hypohydration status assessed using bioelectrical impedance. Measured height and weight were used to determine body mass index (BMI) and weight classification. **Results:** The hypohydration rate was 17% and 94% of hypohydrated firefighters were obese. A one-unit increase in BMI was associated with an 83% greater likelihood of being hypohydrated. **Conclusions:** This study indicates that steady state hypohydration is a significant issue among obese firefighters. Current hydration policies based on previous reports that most (more than 90%) firefighters are hypohydrated in the steady state should be revisited and additional, confirmatory research in this area should be conducted.

Keywords: bioelectrical impedance, hypohydration, obesity, total body water

Firefighting is a very mentally and physically rigorous profession. Firefighters are exposed to several occupational hazards including heat stress and hypohydration, exposure to smoke-borne toxins and medical hazards, having to work in dangerous environments, and managing strenuous physical challenges.^{1,2} A recent assessment of the leading causes of line-of-duty (LOD) deaths from 1994 to 2004 found that more firefighters died from cardiovascular disease (CVD)-related events than any other cause on the fireground.³ In addition, firefighters experience injury rates exceeding most occupational groups, with more than 70,000 LOD injuries in 2011.⁴

Heat stress and hypohydration have been highlighted as primary risks for CVD events and injuries among firefighters.^{1,2,5,6} For example, firefighters involved in fire suppression activities are exposed to both the heat stresses of the fire itself and also having to wear protective equipment, which can result in substantial and fast increases in core body temperature. These rapid increases in body temperature can lead to abundant sweating and hypohydration^{2,6} that, along with the strenuous activity levels involved in fire suppression, result in exacerbated cardiovascular strain (eg, problematic changes in electrolytes concentrations, plasma volume, blood viscosity, and coagulatory properties).^{5,6}

Hypohydration also may result in muscular fatigue and decrements in cognitive function that may increase injury risk.^{1,5}

A number of articles have been written by and for firefighters in industry-related publications about the importance of hydration and the risks of hypohydration to firefighters and a few studies have been conducted on this topic.⁷⁻¹⁰ Bennett et al⁷ reported that among 183 firefighters recruited by the Maryland Fire and Rescue Institute who had useable urine specific gravity (USG) tests, the vast majority (83%) were hypohydrated prior to beginning their training day. Similarly, in a study conducted by the Orange County Fire Authority, 91% of 101 firefighters tested were classified as hypohydrated (also based on USG) prior to beginning their drills and training.⁸ Horn et al⁹ evaluated a convenience samples of 35 firefighters at a local training academy and found that 91% were hypohydrated (based on USG) prior to engaging in any training events. More recently, Raines et al¹⁰ found 75% of a small sample of firefighters ($n=12$) to be hypohydrated (based on plasma osmolality) prior to and after a normal shift even though ad libitum water intake was permitted. These studies suggest that most firefighters are experiencing hypohydration as their normal or steady state.

These few reports and small studies with limited convenience samples provide initial evidence of poor steady state hydration among firefighters (ie, they are hypohydrated even before engaging in relevant occupational activities) that likely increases their risk for significant hypohydration and cardiac stress under the conditions of heat stress and heavy exertion that are typical during fire suppression, rescue, and emergency medical tasks. However, additional data on steady state hydration status are needed from population-based samples to establish the extent of steady state hypohydration among firefighters. Further, evidence is needed on firefighter hydration status relative to firefighter characteristics. For instance, nothing is known about the relationship between firefighter weight status and hydration, which is particularly important given the high rates of overweight/obesity among firefighters¹¹ and the existence of a strong association between weight status and hydration.^{12,13} Therefore, the aims of this study were to establish the extent of steady state hypohydration among firefighters and examine factors associated with their hydration status.

METHODS

Participants and Procedures

This study's protocol was approved by the National Development and Research Institutes, Inc., (NDRI) Institutional Review Board. Data are from the baseline evaluation of a study examining longitudinal risk factors for injury and weight gain among career firefighters from 11 randomly selected fire departments in the International Association of Fire Chief's (IAFC) Missouri Valley Region (Colorado, Iowa, Kansas, Missouri, North Dakota, Nebraska, South Dakota, and Wyoming).^{11,14} Of the firefighters who were available and solicited, 97% agreed to participate and were consented ($N=500$). Greater details about the selection and recruitment process can be found in our previous papers.^{11,14}

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Measures

Body composition, estimated total body water (TBW; in liters), TBW percentage (TBW%), hypohydration status, and body fat percentage (BF%) were determined using a Tanita 300, foot-to-foot bioelectrical impedance analysis (BIA) scale. This device has been validated for estimating TBW against the “gold standard” deuterium and tritium oxide dilution methods, it is reliable and valid when compared with dual-energy X-ray absorptiometry, portable, minimally invasive for participants, and minimizes potential operator error in field epidemiological studies.^{11–13,15–17} In addition, we demonstrated significant concordance between Tanita 300 estimated BF%- and both body mass index (BMI)- and waist circumference (WC)-determined obesity in career firefighters.¹¹

Waist circumference was assessed using a spring-loaded tape measure and height was measured with a portable stadiometer. Body weight was assessed digitally with the Tanita 300. Obesity status was computed using BMI, BF%, and WC using standard cut points.¹⁸ Physical activity level was measured with the self report of physical activity (SRPA) questionnaire, which provides a global self-rating of physical activity patterns ranging from 0 (avoids waking or exertion) to 7 (engages in more than 3 h/wk of heavy physical activity) over the previous month.¹⁹ The SRPA's validity compared with maximal oxygen consumption has been established.¹⁹ Standard individual demographics (eg, age) and occupational history (eg, years in the fire service) also were collected.

Statistical Approach

Data from 22 women firefighters ($n = 21$) and on who did not disclose their sex ($n = 1$) were excluded because this small proportion (4%) precluded our ability to examine the potential moderating impact of sex. Only male firefighters who had TBW estimates at baseline ($n = 450/478$; 94% of the original study) were included in statistical models to examine associations between weight status and hydration.^{11,14} Because we also wanted to determine the temporal stability of our TBW estimates, we computed 9-month (± 1 month) test–retest correlations between baseline and follow-up assessments of TBW and TBW%. Of the 450 male career firefighters with hydration data at baseline, 316 (70%) had hydration data at the follow-up.

Unadjusted means and proportions were computed for TBW, TBW%, and for hypohydration status. Firefighters were classified as either hypohydrated or euhydrated (healthy hydration status) based on their TBW% which was computed by dividing their TBW by their total weight (kg) and multiplying by 100. We could find no definitive standards for defining hypohydration based on TBW%. For example, the Royal College of Nursing (see www.rcn.org.uk) defines the healthy range of TBW% for men as 50% to 65%, so hypohydration is TBW% less than 50% in men. Other investigators have used the lowest quartile in their sample (TBW% = 51% for healthy males).¹⁷ We computed quartiles of TBW% in our sample and firefighters with a TBW% less than 50% were considered hypohydrated.

Crude and age-standardized prevalence of hypohydration (TBW% less than 50%), as well as crude and age-standardized estimates of TBW, were computed using tables from the US Census to facilitate comparison with national estimates.²⁰ StatsDirect Statistical Software version 2.3.8 (StatsDirect Ltd., Cambridge, UK, 2004) was used to compute the age-standardized estimates using the direct method. To explore associations between weight status and firefighters' hydration status, statistical models were developed where euhydrated firefighters were compared with those who were classified as hypohydrated. To examine weight status differences in TBW and TBW%, we constructed adjusted analysis of covariance models.

RESULTS

The 9-month (± 1 mo) test–retest correlations between baseline and follow-up TBW and TBW% were 0.95 ($P < 0.001$) and 0.90

($P < 0.001$), indicating that both estimates were highly correlated and stable over time. In the overall sample, the unstandardized average TBW volume was 49.3 ± 5.3 L and the unstandardized prevalence of hypohydration was 17%. After age-standardization, TBW volume and hypohydration prevalence were 48.7 ± 5.3 L and 14%, respectively.

Table 1 presents the univariate comparisons for all demographic, occupational, body composition, and physical activity ratings by weight status category. As can be seen, there were differences between firefighters in the different weight classes with respect to a number of demographic, occupational factors, and physical activity level. Differences in body composition and hydration variables across the weight status categories were in the expected direction.²¹

Based on the differences noted in Table 1, we developed multivariate models evaluating weight status differences for TBW, TBW%, and hypohydration status, adjusting for age, marital status, race, education, shift type, and physical activity level (body composition variables were not included due to their high collinearity with hydration variables). There were significant differences in TBW between weight status categories ($F = 84.9$; $P < 0.001$), with all post-hoc differences significant between each category. The adjusted means for TBW were 44.7 L (95% confidence interval [CI] = 43.7 to 45.6 L), 48.1 L (95% CI = 47.5 to 48.7 L), 52.1 L (95% CI = 51.3 to 53.0 L), and 56.2 L (95% CI = 55.0 to 57.5 L) for normal weight, overweight, Class I obese, and Class II and III obese firefighters, respectively. TBW% demonstrated the predicted pattern, with those in lower weight categories having significantly greater proportions of their weight consisting of body water ($F = 262.7$; $P < 0.001$). The adjusted means for normal weight (TBW% = 60%; 95% CI = 59% to 61%), overweight (TBW% = 56%; 95% CI = 55% to 56%), Class I obese (TBW% = 52%; 95% CI = 51% to 52%), and Class II and III obese (TBW% = 47%; 95% CI = 46% to 48%) were all significantly different from each other (post-hoc $P < 0.001$).

With respect to the association between weight status and hypohydration, we used BMI as a continuous variable so that the results would be more readily interpretable. BMI was a significant correlate of hypohydration status after adjusting for age, marital status, race, education, shift type, and physical activity level, with each one-unit increase in BMI corresponding to an 83% increase in the likelihood of having TBW% is less than 50% (odds ratio [OR] = 1.83; 95% CI = 1.57 to 2.12). To assess the robustness and consistency of our results, we recomputed all models using a different body composition parameter (WC-defined obesity and WC in cm) and replicated the patterns of associations, with firefighters who were obese based on WC having significantly greater volume of TBW (52 L; 95% CI = 52 to 54 L vs 48 L; 95% CI = 47 to 48 L; $F = 120.7$; $P < 0.001$), but significantly lower TBW% (50%; 95% CI = 49% to 51% vs 57%; 95% CI = 56% to 57%; $F = 317.7$; $P < 0.001$) than those who were not obese. After adjusting for potential confounds, risk for hypohydration status increased 32% for each 1 cm increase in WC (OR = 1.32; 95% CI = 1.23 to 1.42).

DISCUSSION

This study sought to expand and improve the evidence base regarding steady-state hydration among firefighters. In a relatively large sample drawn from randomly selected fire departments, hydration rates were found to be stable over time and significantly associated with weight status. Hypohydration rates were extremely low in non-obese firefighters.

The unstandardized prevalence and age-standardized prevalence of hypohydration in the steady-state were found to be 17% and 14%, respectively. These percentages are considerably lower than those reported by others (83% to 91%).^{7–10} There are several potential reasons for this discrepancy. One is related to

TABLE 1. Demographic, Occupational, Body Composition, and Hydration Differences by Weight Status

Variables	Weight Status				P Value
	Normal Weight n = 89	Overweight n = 210	Class I Obese n = 106	Class II and III Obese n = 45	
Demographics					
Age, yr	35.2 ± 10.5	37.4 ± 9.5	41.8 ± 9.0	41.0 ± 9.1	<0.001
Married (% married or part of unmarried couple)	53 (60)	170 (81)	88 (83)	35 (78)	0.001
White, non-Hispanic (%)	77 (86)	187 (89)	100 (94)	35 (78)	0.032
Education (%)					
High School/GED	16 (18)	23 (11)	5 (5)	3 (7)	0.039
Some College	46 (52)	132 (63)	74 (70)	34 (76)	
College Graduate or higher	27 (30)	55 (26)	27 (25)	8 (18)	
Occupational characteristics					
Rank					
Firefighters	43 (48)	69 (33)	31 (29)	14 (31)	NS
Firefighters/Paramedics	10 (11)	36 (17)	17 (16)	8 (18)	
Driver/Operator	13 (15)	44 (21)	22 (21)	12 (27)	
Officer	19 (21)	48 (23)	27 (25)	9 (20)	
Chiefs	5 (6)	13 (6)	10 (9)	2 (4)	
Years in service	11.1 ± 8.1	13.9 ± 9.3	17.0 ± 8.9	14.5 ± 7.9	
24-hour shift (%)	63 (71)	166 (79)	94 (89)	44 (98)	<0.001
Body composition and physical activity					
Weight, kg	74.4 ± 6.9	86.7 ± 7.5	101.9 ± 7.7	120.5 ± 12.3	<0.001
BMI, kg/m ²	23.4 ± 1.4	27.2 ± 1.4	30.4 ± 3.4	36.4 ± 4.3	<0.001
Body fat percentage; BF% ([fat mass/weight]*100)	17.3 ± 3.4	23.8 ± 3.7	41.8 ± 9.0	41.0 ± 9.1	<0.001
WC, cm	84.1 ± 6.2	93.6 ± 6.2	105.6 ± 6.0	119.3 ± 9.7	<0.001
Physical activity rating (SRPA)	5.0 ± 1.8	4.8 ± 1.8	4.0 ± 1.9	3.5 ± 1.8	<0.001
Hydration status					
Total body water (TBW), L	44.9 ± 3.9	48.3 ± 4.1	52.1 ± 4.5	55.9 ± 4.3	<0.001
Total body water percentage; TBW% ([TBW/Weight]*100)	60.5 ± 2.5	55.8 ± 2.7	51.1 ± 2.7	46.6 ± 3.2	<0.001
Hypohydrated (%; TBW% <50.0)	0 (0)	5 (2)	34 (32)	38 (84)	<0.001

WC, waist circumference.

methodological and/or reporting flaws that raise questions about the validity of previous studies. For example, Bennett et al⁷ reported an 83% hypohydration rate, but indicated that subjects were considered hypohydrated if their USG was less than 1.02; however, an USG greater than 1.02 is the recommended cut point for defining hypohydration.²² Similarly, Espinoza et al⁸ reported a hypohydration rate of 91%, but they also appear to have misinterpreted the criteria—subjects were considered “well hydrated” if USG exceeded 1.02. Although there is no way to determine from the publications how these errors affected their outcomes, it is interesting to note that in both cases the percentage of subjects having a USG over 1.02—indicating hypohydration—was approximately 10% which is similar to our findings.

Methodological variations between studies could contribute to different findings regarding hypohydration rates. We used TBW% to determine hydration status while others used USG. Although both approaches are valid, outcomes can vary given certain conditions and assumptions. First, in previous reports/studies, no mention was made of the exact time of day urine samples were obtained to determine USG. It has been shown that urine samples not taken first thing in the morning may not be accurate indicators of hydration status due to confounding by fluid intake, exercise, and food consumption.²³ Second, as mentioned in the introduction, previous studies used relatively small convenience samples from very narrowly defined geographical areas. We examined 450 firefighters drawn from 11 fire stations randomly selected from a fairly large geographical area. Therefore, it is likely that our sample is more representative of firefighters as a whole and that the rates of hypohydration we observed are closer to what has been found in other large, samples of adults (33% inadequately

hydrated).²⁴ Third, the TBW cut point we used to define hydration status may not correspond exactly with the commonly used USG cut point. It could be that the TBW cut point captured only serious and significant hypohydration. For instance, in the Bennett et al⁷ report the hypohydration rate would be 26% if you only consider significantly and seriously hydrated groups. Finally, in terms of USG, the National Athletic Trainers' Association (2017) defined hypohydrated as a value over 1.02²²; however, Armstrong et al²⁵ suggested 1.026 or greater for hypohydration. Using this value, it is possible that hypohydration rates in previous reports could be more similar to ours.

Adults who are hypohydrated have higher BMIs and are more likely to be obese than hydrated adults.²⁴ Our results support these findings and indicate that among male firefighters, higher BMIs are associated with greater rates of hypohydration. We found that a one-unit increase in BMI was associated with an 83% greater likelihood of being hypohydrated. Nearly 94% of the 77 firefighters we determined to be hypohydrated were obese. Although the exact mechanism(s) for this is not known, it has been suggested that suboptimal water intake, and thus high hypohydration rates, in obese adults is due mainly to lower intake of water-dense foods such as fruit and vegetables.²⁴ Indeed, firefighter have been shown to consume less than recommended daily servings of fruits and vegetables and obtain relatively low percentages of their calories from fruits and vegetables.^{26,27}

Determining the steady state hydration status of firefighters is not only relevant from a hypohydration point of view, but also from a hyperhydration perspective. Water intoxication, also referred to as Hyponatremia, is basically the product of excessive intake of water leading to a low concentration of plasma sodium. This condition has

become more prevalent among athletes who have been instructed to “drink” beyond what their natural thirst dictates.²⁸ The results of previous reports that 90% of firefighters are hypohydrated indicate an urgent need to encourage water intake. However, if these results are inflated due to error, as our study suggests, then the potential to overhydrate is real. It may be wise to revisit current policies calling for aggressive measures to ensure proper hydration among all firefighters.

Hypohydration contributes to cardiovascular strain and is a risk factor for CVD events among firefighters.^{1,2,5,6} However, our results indicate that hypohydration may be but one of several factors that “cluster” and intensify the risk of CVD events among firefighters. The 34% of firefighters in our study who were obese were older and demonstrated higher rates of hypohydration, greater body fat percentages, and lower physical activity levels than non-obese firefighters. Although the presence of multiple risk factors for CVD in firefighters is fairly well-documented, no one has previously associated hydration status with this profile.²⁹ Given the modifiable nature of hydration, especially relative to other disease risk factors (eg, exercise and diet), targeting hydration status among obese firefighters as part of a comprehensive effort to reduce cardiovascular events is recommended.

A strength of this study was the examination of a relatively large sample of firefighters drawn from 11 randomly selected fire departments. The two other peer-reviewed studies in this area used convenience samples of 35 and 12 firefighters.^{9,10} A limitation that should be considered is associated with the approach used to determine hydration status. While BIA has been shown to provide valid estimates of TBW, it utilizes statistically-derived values for predicting TBW, and thus, predictive “accuracy” can vary from application to application.³⁰ Further, as stated in the methods section, widely agreed upon TBW% cut points for defining hypohydration have not been established. However, our use of TBW% less than 50% to define hypohydration is consistent with the literature.

In conclusion, adequate hydration is important for all individuals including those who engage in activities that exacerbate water loss (eg, firefighters during fire suppression). It is well agreed upon that monitoring and maintaining proper hydration during active periods is essential for firefighters. However, extending this practice to steady state periods for all firefighters may not be necessary. Our results suggest that steady state hydration should be of particular concern for obese firefighters and that the rates of hypohydration among non-obese firefighters are very low.

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